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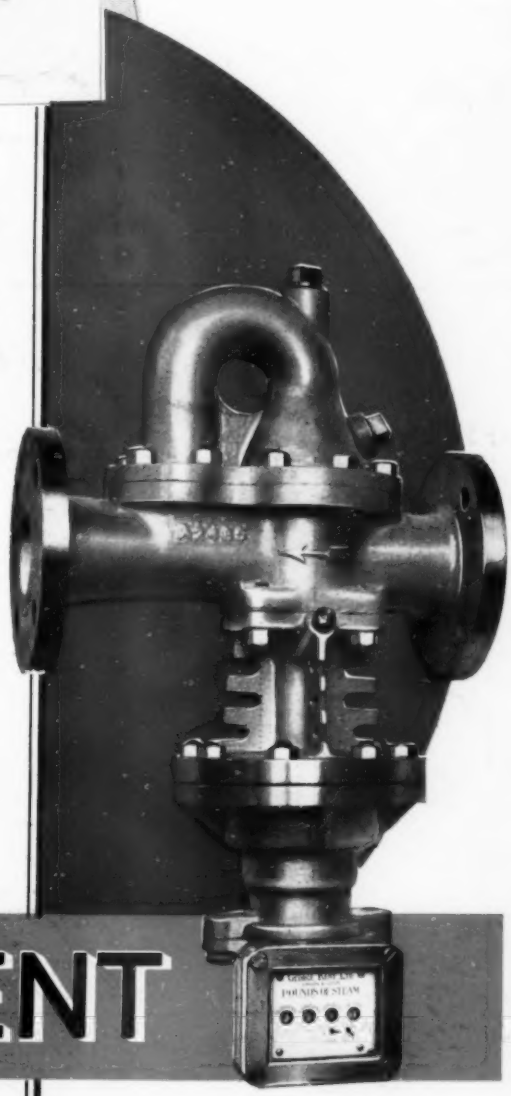

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METALLURGIA

The British Journal of Metals

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PRINCIPAL CONTENTS IN THIS ISSUE:

Page

A Large Gas-fired Installation for the Heat-treatment of Forgings .. 161–163
The problems associated with the heating, cooling and handling of a variety of components are involved, especially when production is on a large scale.

Barium and its Minerals. By L. Sanderson 163–164
Barium is of importance as an alloy with other metals for special purposes; the sulphate barytes is used largely in the manufacture of the pigment lithopone and, when finely ground, as an extender in paints; and the carbonate, witherite, is often a constituent in glass making.

Post-war Reconstruction Based on Price Stabilisation 165

The Austenitic Decay of a Vanadium Steel in an Undercooled Condition 166

Recent Research in Problems of Powder Metallurgy. By D. W. Rudorff, A.Am.I.E.E., M.Inst.F. 167–170
A review is given of recent laboratory research made into certain theoretical and practical problems of powder metallurgy. Research of this kind is of particular importance in view of the existing gap between practical experience and theoretical knowledge in this field. Comments specially contributed by Dr. E. A. Bánó are also given.

Corrosion Fatigue of Notched Cast-iron Specimens 170
Results are given of some recent corrosion fatigue experiments on un-notched and notched specimens of cast iron.

The Formation and Properties of Martensite on the Surface of Rope Wire. By E. M. Trent, M.Met., Ph.D. 171–174
The occurrence of thin layers of martensite on the worn surfaces of wires in wire ropes used in mining is described.

Complex Copper-Cobalt-Silicide Alloys 174
Results are given of experiments carried out on two copper-cobalt-silicide alloys, one having beryllium added and the other phosphorus, in order to investigate the combined effects of cobalt silicide and cobalt beryllide, and cobalt silicide and cobalt phosphide.

Page

High Temperature Metallic Resistor Furnaces 175–177
The usefulness of high temperature metallic resistor furnaces was formerly limited to laboratory experiments, but recent developments in materials and products requiring high temperature treatment have directed attention to the use of metallic resistors in furnaces large enough for plant practice.

Unsoundness in Gravity Die-cast Silicon-Aluminium Alloy Pistons 177

Atmospheric Exposure Tests on Copper-bearing and other Irons and Steels in the United States 178

The Practice of Marketing Aluminium. Part III. By R. J. Anderson, D.Sc. 179–181
The marketing of aluminium and its manufactures when hostilities cease will necessarily be conditioned by the kind of products and their field of use, and future developments will increase the range.

Organic Finishes on Zinc-Base Die Castings. By E. E. Halls 182–186
Two main types of chemical pre-treatment, to render the surfaces of zinc die castings inert, are discussed, and results are given of tests carried out on the relative merits of each process.

Hot-Tinning Cast Iron 186–187
Coating metals with tin by dipping them into the molten metal is still the most widely used method of tinning. In this article the hot-tinning of grey cast iron is discussed and the need for care in the preparation of castings is emphasised.

Quenching Stresses in Aluminium Alloys 187

Developments in Metal Extrusion .. 188
As a result of ceaseless metallurgical research and improved hydraulic presses, stainless steels, nickel alloys, bearing steel, etc., are now extruded.

Reviews of Current Literature 189–190
Empire Mineral Resources and their Relation to the War Effort. The Sampling and Chemical Analysis of Cast Ferrous Metals. Chemical Analysis of Aluminium.

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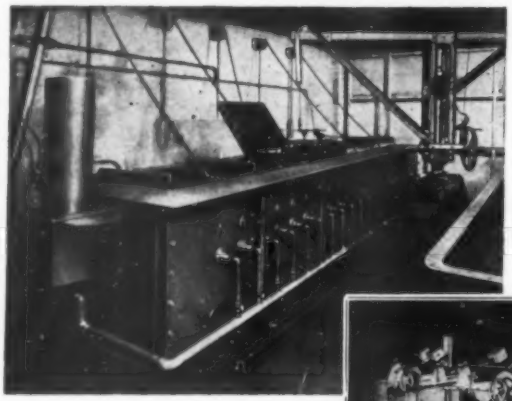

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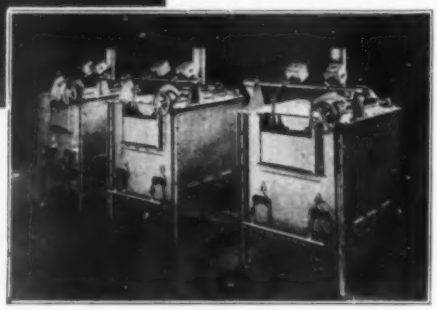

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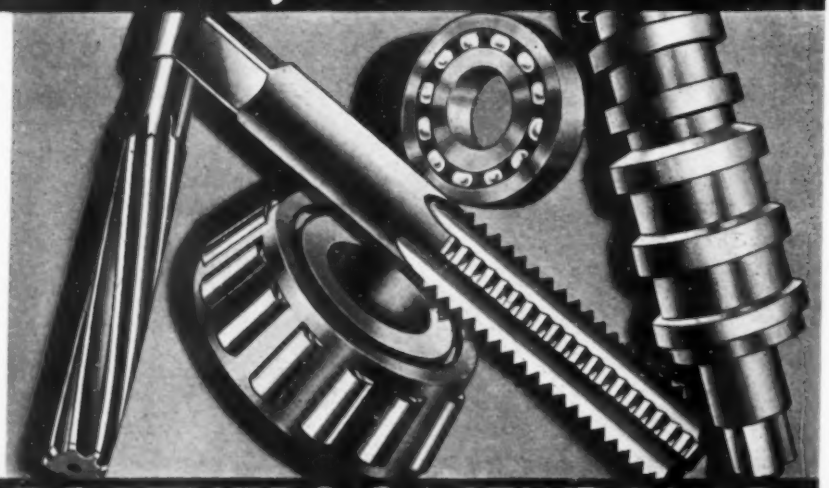

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METALLURGIA

THE BRITISH JOURNAL OF METALS.
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APRIL, 1941. VOL. XXIII, No. 138.

A Large Gas-Fired Installation for the Heat-Treatment of Forgings

The problems associated with the heating, cooling, and handling of a variety of components are involved, especially when production is on a large scale. There are no fixed standards to determine the type, size, number, and layout of the units in an installation best adapted to requirements. In this article a recent installation of batch type furnaces is described.

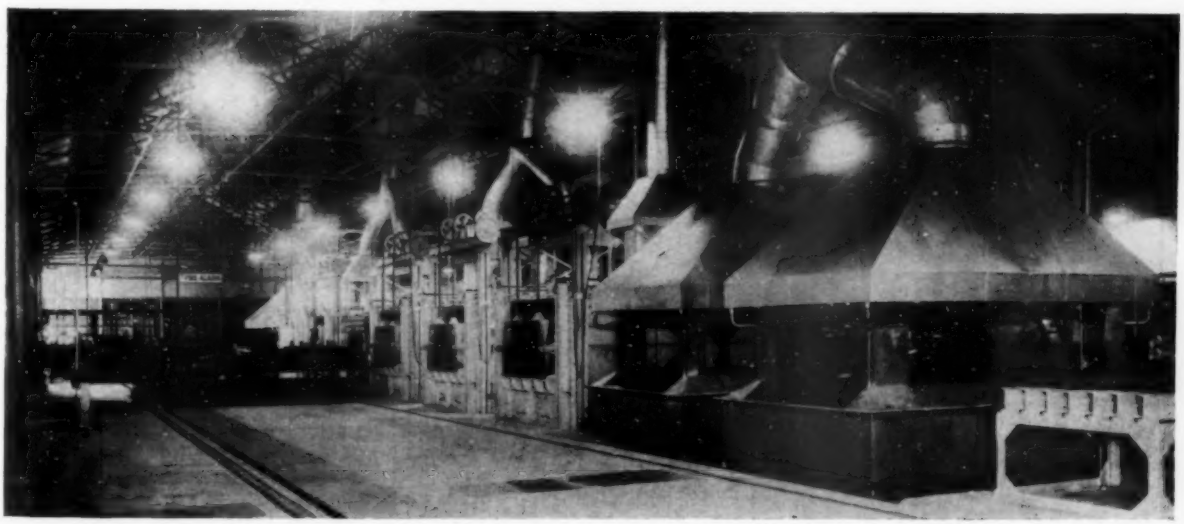
MANY variable factors affect the quality and over-all cost of heat-treated components, hence there are no fixed standards to determine definitely the proper form of heating or cooling equipment or the form of fuel or electricity to be used. Selection is primarily a problem of devising a suitable method of heating, cooling, and handling the components to be treated under specific plant conditions, and consideration of these factors is necessary to determine the type, size, number, and layout of the heating and cooling units ; the auxiliary equipment, and the heating medium best adapted to satisfy requirements. The problems involved in handling a variety of components, especially on a large production scale, are considerable. The selection and design of equipment is frequently a compromise between the ideal and the practical in reconciling requirements of quality with conditions relating to methods to be employed, variations in size and quantity of components, etc., and the problems have been solved in many ways.

For the smaller components, when the time required for heating is not unduly long, a continuous type furnace, of either mesh belt, roller hearth, pusher, walking beam, rotary or other type may be used for the hardening portion of the cycle. The parts can be directly dropped into the quenching medium and then lifted out periodically by means of a basket. Alternatively, automatic conveyers have been designed for the continuous removal of quenched articles from the tank, from which they can be directly transferred to a tempering furnace which may also be of a continuous type.

When the heating cycle is a long one, continuous furnaces are somewhat at a disadvantage, as their dimensions would necessarily be of unwieldy proportions to permit an output figure consistent with economic operating conditions. Other considerations make it advisable to revert to the use of batch type furnaces, which, when operated under correct conditions, give very uniform results and leave little to be desired in regard to either quality or quantity of production.

Fig. 1 shows a general view of a complete heat-treatment installation by the Incandescent Heat Co., Ltd., in which batch type furnaces and mechanically operated charging and quenching equipment have been used to the best advantage. Each furnace has a capacity of approximately 1 ton per charge of forgings weighing from a few pounds up to several cwts. The bulk of forgings require a 2–3-hour soak at temperatures varying from 850°–910° C., followed by an oil quench. In some cases normalising for 2 hours is carried out. The forgings are tempered at 600° C. and facilities are provided for water quenching if required.

Fig. 1.—A general view of the complete heat-treatment installation, showing batch type furnaces and mechanically operated charging and quenching equipment.



As rapid handling of the load is a very essential feature if the furnaces are to be continuously maintained in production, a high-speed electrically operated charging machine is provided. A ton load of forgings is completely charged or discharged in 5 seconds and the load may be rapidly transported from the furnace to the nearest quenching tank as the machine has a maximum traversing speed of 250 ft. per min. when fully loaded.

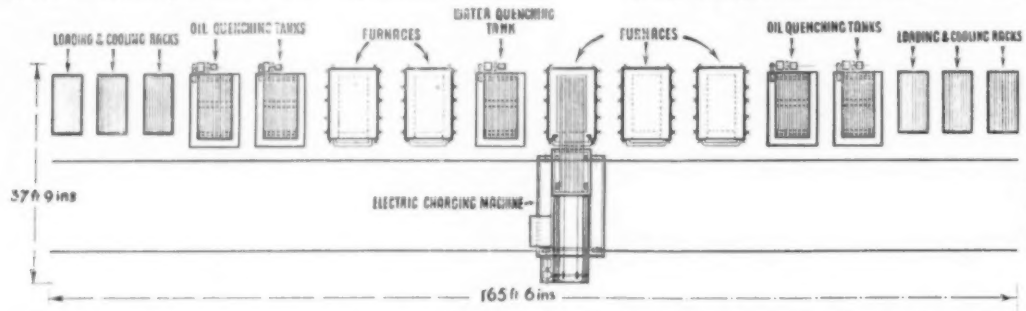


Fig. 2.—Showing the arrangement of the complete installation.

The general layout is shown in Fig. 2, from which it will be seen that no furnace is unduly distant from an oil or water-quenching tank. The complete plant consists of a battery of five batch type heat-treatment furnaces, together with four oil-quenching tanks and one water-quenching tank; three loading, and a like number of unloading racks, and a specially designed electrically operated high-speed charging mchine.

Design of Furnaces

The five furnaces used are all of the patent incandescent deep recuperative under-fired natural draught type, having clear inside working dimensions 10 ft. long by 5 ft. wide by 2 ft. high. These furnaces are fired by burners of the inspirating type, which fire into individual chambers below the hearth. Pre-heated secondary air is employed so that complete combustion takes place before the gases enter the furnace proper. The gases travel to vertical regulatable uptakes on each side of the furnace, and are finally withdrawn to waste gas flues near the door opening, and then travel through deep recuperators built below the hearth. It is through these recuperators that the incoming secondary air is heated.

Counterbalanced doors operated by geared hoisting tackle as is seen in Fig. 3 provide easy opening and closing of the furnace door. In addition to the refractory lining, the side walls are heavily insulated, minimising heat loses. Each furnace is automatically controlled, the controlling equipment being situated on the rear wall. A central control panel shown in Fig. 4 carries five indicating pyrometers, whereby the temperature of each furnace can be seen at a glance, whilst a multi-point recording pyrometer provides a continuous record of the temperature of each furnace.

Charging Equipment

An interesting feature of the installation is the electrically operated charging machine, which travels on rails along the entire length of the plant. A view of the charging machine is included in Fig. 3, showing a load of forgings being charged into the furnace. The load is placed on landing walls inside the chamber, the charging forks withdrawn, and the door closed.

For unloading and quenching, this cycle is reversed; the forks run into the furnace between the hearth piers, the load is raised, withdrawn and rapidly conveyed to a quenching tank, where the work is transferred on to a table constructed of steel sections corresponding to the landing walls of the furnace hearth. An overhead drum gear operates the table and lowers the load smoothly and quickly into the oil.

The charging forks have a total reach of 12 ft., and carry an evenly distributed load of 1 ton of forgings. Although large forgings may be placed directly on to the loading tables (which are constructed of 9 in. × 4 in. steel joists spaced similarly to the landing piers of the furnace hearth and quenching tank equipment) and then transferred by the charging machine as required; smaller parts have to be loaded on to perforated trays, preferably made of nickel-chrome alloy.

Loading Mechanism

The "in" and "out" motion of the forks is by means of two endless chains running over sprockets driven by motor and reduction gear; the control is arranged for operation by an automatic electric push-button started from the driving platform in conjunction with limit switches and an electrically operated brake on the motor shaft to prevent over-running.

The lifting action of the carriage runway is by means of toggle levers operated from a motor through reduction gear and crank; this results in continuous rotation of the motor being maintained, the "up" and "down" positions

Fig. 3.—A view of the charging machine; note also the counterbalanced doors which are operated by geared hoisting tackle.

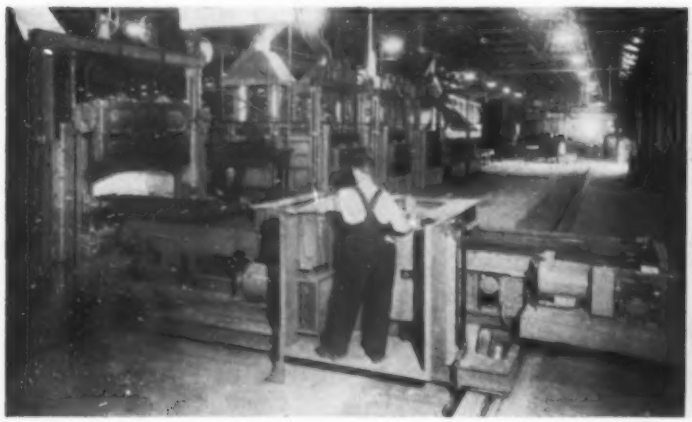
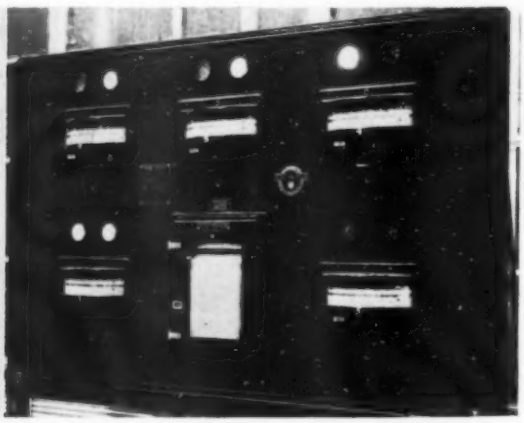


Fig. 4.—The "Electroflo" control panel which carries five indicating pyrometers and a multi-recording pyrometer.



being controlled by limit switches and an electro-mechanical brake. The toggle levers in the vertical position provide a mechanical lock to relieve the brake load. The carriage is controlled by four guide rollers, to give perfect alignment during its operation.

The machine traverse is effected by a variable speed-drum control driven by a motor through reduction gear. The controller is fitted with a conventional type "dead man" operating handle as an approved safety device. A maximum running speed of 250 ft. per min. can be obtained, and it has actually been found possible to quench a load from furnace most distant from the nearest oil tank in a time of 21 secs.

Quenching Tanks

These tanks, two of which are illustrated in Fig. 5, are 12 ft. long by 6 ft. wide by 8 ft. deep, and have side extensions and splash plates to run off the overflow. Each tank has a capacity of 15 tons (3,500 gals.) of oil, which gives ample quenching volume for the load. The charge is raised and lowered on its rack by means of wire rope suspension from overhead drums driven by motor reduction with limit switches. The actuating mechanism at the rear of the tanks can be seen on the right in Fig. 4.

Excessive heating of the oil is provided against by means of oil coolers through which the oil is continuously circulated. Hoods are provided over the oil tanks and fumes are withdrawn by fan exhausts located inside the ducting leading from these hoods. The method of lowering the forgings into the oil in a fixed time has the advantage that during the whole of the lowering time fresh oil is being constantly brought into contact with the load, not only by the convection currents set up during cooling, but also by the steady mechanical motion of the work through the oil. In this way, a very uniform cooling rate is attainable.

If necessary, the load can be given a reciprocal motion up and down through the oil after it has reached its lowest point in the quenching tank by suitably manipulating the control buttons.

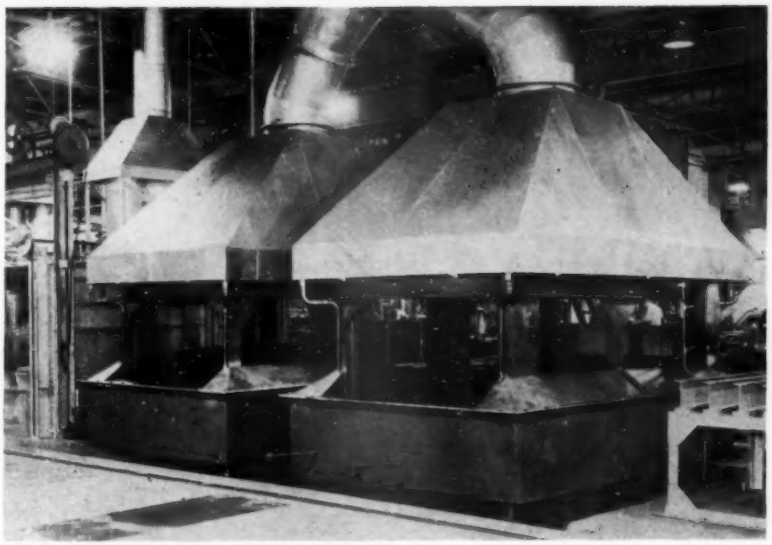


Fig. 5.—Two of the quenching tanks in the installation, each has a capacity of 3,500 gals. of oil.

Barium and its Minerals

By L. Sanderson.

Barium is of importance as an alloy with other metals for special purposes; the sulphate barytes is used largely in the manufacture of the pigment lithopone and, when finely ground, as an extender in paints; the carbonate, witherite, often is a constituent in glass-making. Particulars are given of these minerals together with brief notes on the history of barium.

BARIUM takes its name from barytes, the chief commercial source of the element. Consideration of its history we will defer for the moment and examine first the element itself and its main sources. There are two, namely, barytes, as already mentioned, and witherite. Barium itself possesses a white metallic sheen, but if nitrogen enters into its composition, its white appearance is tinged with yellow. Its melting point is approximately 850° C. Its specific gravity is 3·78. It has the attribute of volatilisation when placed in a vacuum, so that sublimation is not a difficult matter, while if subjected to heat it quickly combusts, leaving the residue barium oxide (BaO). In its metallic form it is readily oxidised, and although there is a good market for this form, the metal cannot be used successfully for the purposes for which it is required unless it is protected from the air and thus from oxidation.

Barytes (barium sulphate—$BaSO_4$) is obtained from two large producing countries, one being Germany, the other the United States of America. Two other nations have reasonable deposits of commercially exploitable barytes, and other deposits exist—e.g., in India—which the cutting off of the German supply may cause to be developed. The two nations mentioned are Great Britain and Italy.

Witherite (barium carbonate—$BaCO_3$), on the other hand, is exclusively a British source, and the main deposits are situated in Durham and Northumberland. From these are obtained adequate supplies of natural barium carbonate, which is a commodity not excessively in demand. Other deposits exist in Devonshire, Shropshire, Derbyshire, Yorkshire, and Westmorland. Outside Great Britain, there are no witherite mines actively exploited, but the situation is entirely different with barytes. Smallish production occurs in Southern Rhodesia and the Union of South Africa. Some barytes have been produced in Canada and Nova Scotia, though not sufficient to constitute a serious factor in the world market. A little has been worked in Newfoundland. India and Burma possess deposits that might at any time reward commercial exploitation on a larger scale than has as yet been attempted. The same is true of Australia, and particularly of South Australia, where production has steadily risen, since 1923.

Belgium and France, once active and important producers, have slowly reduced their output. In France, between 1930 and 1934, for example, production declined by nearly one half. Germany, the largest producer in the world, had an output of 341,758 tons in 1935, as against 200,992 tons, the output of the United States in the same year. Greece and its islands have large undeveloped

deposits, and in 1935 was beginning to produce a fair quantity (approximately 5,000 tons a month). Italy's figure for 1935 was 40,502 tons. Great Britain in 1935 produced 78,132 long tons of barium minerals, but this figure includes a large output of witherite. Spain is a producer, though a less important one than Italy. The U.S.S.R. is claimed to have vast reserves of barytes in the Urals and elsewhere, some of which are certainly being actively worked on an increasing scale. Accurate figures are, however, lacking. A little of the mineral comes from Brazil, and China,

The production of barytes involves not only the extraction of the mineral from the mine, but also its preparation for the market, which means a certain amount of dressing. The methods adopted and the amount of dressing vary considerably with the extent of the deposit and the quantity produced. In America, for example, the large output warrants the installation of more extensive dressing plant. There the barytes on being brought from the mine is screened in grizzlies and rotary screens, then washed free from clay in log washers, afterwards crushed and jigged, and finally the concentrating tables are employed to deal with the fines. In British barytes mines, in a typical instance, the raw material is reduced in a jaw crusher, and then passes over a trommel screen, which eliminates all material $\frac{3}{4}$ in. and under. Material above this size passes to a set of crushing rolls, which reduce it and transference to a trommel screen then takes place, the material being screened down to five different sizes from below $\frac{1}{16}$ in. up to above $\frac{1}{4}$ in. Each of these sizes is jigged to free the barytes from impure matter, and from each series of jigs three or four grades of different degrees of purity are had. In other mines, roller mills grind, classify, and convey the material in one automatic operation.

Bleaching has to be carried out if the barytes is discoloured, especially when it is required for paint manufacture. In the United States bleaching is not often required, owing to the good colour of the mineral. In Great Britain, sulphuric acid and steam are used. Twenty tons of the mineral are dumped into vats with a lining of lead. Into these vats sulphuric acid of 15% concentration is pumped, and steam is then blown in. When the process has attained its end, the acid is drained off from the tanks and stored for further use, after which the bleached barytes is washed with hot water and then several times with cold water. The contents of each vat are next dried in a special drying room, where the material is spread over floors which have a slightly conical form. A number of radial arms carrying furrowing instruments like ploughshares slowly drive the material to the outer edges.

Witherite also requires dressing. As it comes from the mine, it is sorted by hand for quality and cleanness. The best quality needs no dressing, and is marketable as it stands. The lower grades are passed through a jaw crusher, which breaks them down to pass 1 in. mesh, and they are afterwards concentrated by special jigs.

Barium itself is prepared by heating barium oxide (BaO) and peroxide (BaO_2) to 1,350° C. in an electric furnace, with a metal having a high heat of oxidation, aluminium being frequently employed for this purpose. There are numerous uses for barytes and witherite, but with these, in this article, we will not deal, since it is barium with which we are concerned. The metal, as such, is a highly active deoxidiser. It enters into combination with numerous gases, and is used to some extent in the radio industry, in filament form, coated with copper, being thrust into radio valves to remove by its ready oxidation the last traces of gas. Care has to be taken to ensure that the metal is not deposited on the electrodes, as otherwise the valves would emit undesired noises when in operation.

Barium is principally of importance as an alloy. With lead and calcium it forms a barium-bearing metal (the barium content being about 2%). With aluminium and magnesium separately it forms a highly fluid alloy used in the radio industry for valves. Alloyed with nickel, it has been used for sparking plug electrodes because of its high resistance to the corrosion from heated gasses. Barium nickel alloys have also been used for the base wires of radio valve filaments.

Barium carbonate used as an ingredient in glass is claimed to confer important advantages—e.g., a higher refractive index, greater brilliancy, elasticity and toughness. It constitutes a good flux in the making of enamels, and is recommended as a rat poison, when mixed with oatmeal and a flavour.

Barium peroxide is used in making hydrogen peroxide. Barium chloride is employed in preparing lake colours, as a mordant in fixing acid dyes, and is used in leather and textile manufacture. Barium hydrate has an important part to play in the manufacture of sugar from beet, where it serves as a chemical extractor of the sugar from the molasses. It is also used in making barium soaps used in paint, polish, linoleum and cellulose lacquer manufacture. Barium nitrate is the ingredient that gives a brilliant green light in fireworks and signal lights. Barium sulphate or "permanent white" is a most valuable base for making colours of great brilliancy. It is also used in making a base for coal-tar dyes, as a filler for enamel paints, and for making grease paints and cosmetics.

Lithopone, which is a blend of barium sulphide and zinc sulphate, is a valuable and widely used pigment.

A few notes on the history of barium may not be out of place. Barytes was first investigated in 1602 by V. Casciorolus, a shoemaker of Bologna, in Italy. This man discovered that when ignited with combustible substances it became phosphorescent, and for this reason was often entitled Bolgonan phosphorus. In 1774, K. W. Scheele, studying pyrolusite, discovered a novel material in the mineral. This, on being treated with sulphuric acid, produced an insoluble salt that was later proved to be identical with a salt occurring in heavy spar or barytes. For a long time efforts were made to isolate the metallic barium, but these were not very successful. Sir Humphry Davy, for instance, tried to electrolyse baryta, but failed. At a later date he endeavoured, by employing barium chloride in the presence of mercury, to produce an amalgam. In this he succeeded, and the amalgam of barium and mercury was the basis for a distillation process in which the mercury was distilled away, leaving metallic barium in the form of a silvery white residuum. There is still some doubt whether Davy did, actually, achieve success in this way. Bunsen in 1854 electrolysed a thick paste of barium chloride and dilute hydrochloric acid in the presence of mercury at 100° C. This produced an amalgam of barium and mercury, from which the mercury was distilled.

In 1901, a still further method was adopted by Guntz, who electrolysed a saturated solution of barium chloride employing a mercury cathode. By this means he obtained a 3% barium amalgam, which was promptly transferred to an iron bar in a wide porcelain tube. This tube was then slowly heated by electrical means, with the result that a fair quantity of barium was obtained at a temperature of approximately 1,000° C.

Barium and its salts are speedily detected because when moistened with hydrochloric acid and heated in a Bunsen flame they show a yellowish green colour. Another method of detection is examination of their spectra, which reveal two typical green lines.

Barium has three oxides. The first, barium monoxide, has the chemical formula (BaO); the second, barium dioxide, has the formula (BaO_2). The third is a suboxide. A characteristic of the metallic element is that it speedily attacks water and alcohol, while it is soluble in liquid ammonia. Its hardness is a trifle above that of lead.

The actual name "barytes" is derived from a Greek word *baros* which means heavy, hence barium, which is found in barytes or "heavy spar," as it is called. In addition to barytes and witherite, two other minor sources not previously mentioned are baryto-calcite and baryto-celestine.

METALLURGIA
THE BRITISH JOURNAL OF METALS.
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Post-War Reconstruction Based on Price Stabilisation

IN normal times the future possibilities of industry as a whole, or of its individual sections, may be assessed with a reasonable degree of accuracy and preparations made accordingly. This is possible, because in such times conditions are more stable. Changes do, in fact, take place, but generally they take effect so slowly as to be almost imperceptible. Under conditions of war, planning for the future is much more difficult, particularly when it is a war that threatens to destroy the progress of mankind for hundreds of years, yet we must plan for the future in times of war, because the major part of industry and of the adult population are concentrated on specialised war efforts and almost complete reorganisation will be necessary to change over to peace-time conditions.

War brings fundamental changes, and we can be certain that these changes will greatly affect each section of industry. While it would be futile to indulge in prophecies, at the end of the war we shall face a new world, and unless the best brains of this country are directing at least part of their energies to post-war reconstruction, the new world will be one of chaos. The problems, for which solutions must be sought, are many and all are complex. Industrial problems alone will be difficult of solution, for industry will have to decide what to do with the excess manufacturing created by war conditions and at the same time find employment for millions of men and women now in the Forces. It must be remembered also that thousands, who have been specially trained and are now engaged on products for the Forces, will remain in their new occupation.

The outstanding facts of the present situation are that tens of millions of people, having ceased production of utility goods, are concentrating on destruction—while within the actual war zone vast reserves of real wealth in all forms are disappearing. Normal production, trade, transport and finance are disrupted as never before. Acute shortages of basic necessities face whole populations in many countries. Yet the productivity of the earth and the productive capacity of men will remain.

Primary production, in addition to yielding the greater part of our food and fuel in natural form, is the basis of all processing, manufacturing, trade, finance and ancillary enterprise. It is the sole foundation for world economy, thus, if world economy is to be stable, it must have stability in primary industry as its base. With this in view far-reaching proposals were made by Mr. L. St. Clare Grondona at a recent meeting of the Royal Empire Society organised by the Institute of Export. He submitted that the first task of reconstruction should be to ensure world-wide price stability for primary products over an appropriately wide field. Thereby, even before tangible results were produced, a spirit of world-wide confidence would replace the bewilderment which would otherwise seem inevitable—which is, in fact, already being experienced in certain primary producing countries outside the war zone.

For many years prior to this war, the primary producer lived and worked in an atmosphere of demoralising uncertainty. The fluctuations in prices of certain raw materials since the last great war are cited, and each product mentioned has a constant utility value. For instance, bread is of the same utility value to men whatever its cost may be, and the same is true of wool, cotton, iron, lead, tin and hundreds of other essential products. It is absurd that the price of wheat should average 7s. 6d. a bushel throughout one year and 3s. 4d. throughout another. The price of sugar as high as 25s. 9d. and as low as 4s. 8d. a cwt., of wool 6s. 4d. per lb. down to 1s. 10d., of tin £300 a ton down to £118, and of copper £118 a ton down to £30. These are cited, not as freak figures, but as officially recorded annual average prices of recent years.

Excepting wasting assets, such as minerals (and apart from marine products), primary wealth is usually in the form of perennial increments of the soil; and in respect of these, nature demands intelligent co-operation from men if she is to yield a full measure of her bounty. And such intelligent co-operation cannot be given unless the producer can plan ahead for a reasonable period, unless he has a guaranteed market at prices which, at their minimum, safeguard him against actual loss, which, at their average, give him a profitable return, and which, at their maximum, are not beyond the purchasing power of the average consumer.

Mr. Grondona's main proposal is that Great Britain alone can impart this stability to primary production by the establishment of a Price Stabilisation Corporation adequately financed and operating, in relation to a wide range of primary products, in a manner very similar to the functioning of the Bank of England prior to 1914. In those days the Bank was always prepared to buy gold at 77s. 9d. per standard ounce, and to sell it in any quantity at 77s. 10½d. per standard ounce—two figures known as the "gold points." Thus, fluctuations in the open market price for this metal was limited to 1½d. per ounce, and apart from freight and insurance the price of gold was thereby stabilised throughout the world, because no one would sell gold at a price lower than that which he would realise in London; and no one would pay more than it cost him if he bought from the Bank of England.

Subject to the very important proviso that the Price Stabilisation Corporation would adjust its buying and selling prices with due notice and in the light of changed conditions, it would be a sort of Bank of England dealing not in gold, but in goods which have a constant utility value. All grains, pulse, nuts, seeds, textile and fibrous raw materials, oils, fats and waxes, industrial metals and many other products—whatever their source—would come within range of the scheme. While the primary producer would be safeguarded from the outset, the interests of the wholesale consumer would be correspondingly protected as soon as reserves were in Corporation ownership.

Mr. Grondona urged that the Corporation should be set up without delay for the purpose of establishing reserves in several overseas primary producing countries in which surpluses were now accumulating owing to loss of European markets. The goal suggested was that this country should acquire at least £500 million worth of such products as would be in unprecedented demand here and in Europe after the war. Great Britain would thus be in a position to make loans available in kind to hasten our own and Europe's recovery, and the Corporation's ownership of such vast stocks would enable it to control the range of future price movements within reasonable limits.

It is contended that, by the adoption of this scheme, all currencies would ultimately be exchangeable for known quantities of standard utility products, and at that stage

there would be stability in foreign exchange to almost the same extent as when all great nations were on the gold standard.

This scheme offers definite means of facilitating the solution of many of the difficulties of post-war reconstruction, which will confront not only Great Britain and the Overseas Empire, but all European, and many other, countries, and the proposal can be regarded as an outstanding contribution to the solution of problems that confront the nation when hostilities cease.

Bessemer Gold Medal, 1941

The Council of the Iron and Steel Institute announce that at their meeting held on March 20, 1941, they decided unanimously to award the Bessemer Gold Medal for 1941 to Dr. T. Swinden, of the Central Research Department, the United Steel Companies, Ltd., in recognition of the value of his original investigations in the metallurgy of steel, and of his eminent services in the organisation and direction of research in the steel industry.

Formation of Anodic Coatings on Aluminium

Anodic coatings on aluminium and its alloys continue to offer a fruitful field of research from the commercial as well as the strictly scientific viewpoint. Their widespread and rapidly increasing use has stimulated interest in their properties and the manner of their formation and the results of a recent study of the latter aspect is reported by Edwards and Keller,* in which it is stated that anodic coatings formed on aluminium in dilute solutions of sulphuric, oxalic, chromic and boric acids are, as far as can be determined by X-ray and electron diffraction methods, amorphous. They are composed chiefly of aluminium oxide, but also contain substances adsorbed from the electrolyte. Coatings formed in boric acid electrolyte are substantially impervious and non-adsorptive, whereas those formed in sulphuric, oxalic and chromic acid electrolytes are porous and adsorptive. The porosity in the latter type of coating is attributed to the solvent action of the electrolyte and this porosity is thought to be responsible for the adsorptive characteristics of these coatings. The presence of pores permits the continuous passage of current; consequently, coatings made in these electrolytes can be produced with a substantial thickness.

For the electrolytes investigated, the anodic oxidation process is about 100% efficient as far as the conversion of aluminium to oxide is concerned. As a result of the solvent action of the electrolyte on the oxide, the apparent current efficiency in terms of oxide remaining as coating is shown to be as low as 50% or less. Microscopic examination of especially prepared cross-sections of anodically coated aluminium shows evidence that the oxide has a cellular structure. The fact that the oxide occupies a larger volume than the metal from which it is formed is demonstrated visually. The increase in thickness resulting from the application of an anodic coating must be considered where close fits are required between coated parts.

Obituary

It is with great regret that we have to record the death at his home, at Somerfield, Holmfirth, near Huddersfield, of Mr. Francis Edwin Brown, chairman of Messrs. David Brown and Sons (Huddersfield) Limited), and its associated companies.

Mr. Brown, who was 67 years of age, was a pioneer in the development of machine-cut gearing. After realising the possibility of cutting teeth and applying his methods to actual running gears, he pressed forward every phase of development in both plant and methods. He stimulated much research work on helical gears and the plant for producing them.

His passing leaves a gap in the engineering world that will not easily be filled.

* J. D. Edward and F. Keller. The Electrochemical Society General Meeting, April, 1941. (Advance copy.)

The Austentite Decay of a Vanadium Steel in an Undercooled Condition

THE results of an investigation on the austenite decay of a vanadium steel in undercooled condition; the rate of decay and the structure dependent on previous treatment and on the temperature at the time of decay, are given by Wever and Lauge.* The investigation is considered as a continuation of a former one by Wever and Rose, reported in the January, 1940, issue of this journal, page 82.

A vanadium steel of 1·02% vanadium and 0·78% carbon has been investigated in the uncooled condition by means of a magnetic balance, and the austenite decay has been observed as depending on the starting temperature. The transformation took place in three stages: in the first, from about 700° to 540° C., pearlitic and troostitic structures arose; in the intermediate stage of 540° to 350° C. the structure consisted of parallel needles, and the third stage resembled the martensitic formation.

The course taken by austenite decay has been investigated—when the starting temperatures were 1,180°, 1,120°, and 1,015° C. The vanadium carbide, which is not dissolved at the low starting temperatures, had the effect of forming nuclei in the two upper stages and diminished the duration of the transformation; the structure became finer the more the starting temperature decreased. With the starting temperature of 1,015° C. the stages of transformation can just be distinguished from the transformation curves, but not from the structure. The dependence of the maximum of the rate of transformation on the temperature of the decay remains, however, unchanged for different starting temperatures; the measure of the rate of transformation only showed an essential difference.

The phases originating from the decay were investigated by a magnetic method. It is stated that always, in the upper as well as in the intermediate stage, equal quantities of ferrite, vanadium carbide and cementite developed without being appreciably soluble in each other.

The transformations of the upper and of the intermediate stages were influenced by a precipitation of ferrite and cementite respectively.

* Communication to the Kaiser-Wilhelm-Institut für Eisenforchung zu Düsseldorf, Vol. XXI, No. 3.

Polynary Magnesium Alloys

THE working qualities of magnesium are improved, as has been known for a long time, by alloying with a variety of light and heavy metals, and excellent examples of the improved products are the magnuminium alloys discussed in METALLURGIA of May, 1940. Rather different in respect of the alloying components, but comparing favourably in strength and ease of fabrication are the series of new magnesium alloys, in which the light metal is alloyed with silver and calcium (or other alkaline earth metal), together with one (or more) heavier metal. In the table below are given the percentage compositions of some of the latest additions to this range of alloys, with strength data relating to the annealed rolled sheet material:—

Ag.	Ca.	Mn.	Zn.	Cd.	Sn.	Yield Strength, Lb. per Sq. In.	Tensile Strength, Lb. per Sq. In.	% Elongation.
3·2	0·3	0·8	0·9	—	—	26,000	39,000	18
1·1	0·2	1·1	3·3	—	5·1	23,000	39,000	15
3·4	0·3	1·4	—	—	5·1	24,000	37,000	10
0·9	0·3	—	0·9	4·7	—	30,000	41,000	19
0·9	0·3	—	0·9	—	—	26,000	36,000	17
0·9	0·3	1·4	4·5	4·8	—	31,000	45,000	14
3·2	0·3	0·8	0·9	—	—	26,000	39,000	18
0·9	—	1·5	4·8	5·7	—	29,000	44,000	16

The general procedure in making these alloys is to add the alloying metals to the bath of molten magnesium, the calcium being stirred in last with avoidance of excessive stirring to prevent loss of calcium in the flux. In regard to the composition of the flux the presence of magnesium chloride is permissible when the calcium content is less than 0·3%, but in other cases it is preferably omitted. (U.S.P. 2,221,243–2,221,259, Dow Chemical Company.)

Recent Research into Problems of Powder Metallurgy

By D. W. Rudorff, A.Am.I.E.E. M.Inst.F., F.R.S.A.

A review is made of recent laboratory research into certain theoretical and practical problems of powder metallurgy. Research of this kind is of particular importance in view of the existing gap between practical experience and theoretical knowledge in this important field. While the review refers in particular to the work of M. Y. Balshin, carried out in Russia, some comments specially contributed by Dr. E. A. Bánó, London, are also included.

THE pressing process may be said to represent one of the most important stages in the process technique of metal ceramics. In view of the many important problems which are barring the way to further important advances in this most promising branch of metallurgy, a thorough theoretical and experimental clarification of the pressing process appears to be of vital necessity. In this connection, the extensive research undertaken by M. Y. Balshin*, is of great importance, and a review of his findings will therefore be of interest.

In his endeavour to place the analysis of the pressing process upon a scientific basis, Balshin is especially concerned with the elimination of certain erroneous ideas which are liable to create entirely misleading conceptions in minds insufficiently trained in theoretical physics. Pointing to one of the most glaring misconceptions in this respect, Balshin speaks of the fairly common error that, for identical pressures, the density of the compressed piece increases with decreasing size of the powder particles, because the cohesive forces increase with decreasing particle size. But, in reality, energy must be expended upon overcoming the forces of cohesion. Thus, in the majority of cases, the density of the pressed piece decreases with increased fineness of the powder.

In Dr. Bánó's view this may be so in the case of spherical particles which are subjected to atmospheric pressure only. As a matter of fact, it is known that the total porosity of a loosely-heaped powder increases in most cases with the grain fineness of the powder; but this is due first of all to geometrical reasons. When mechanical pressure is applied and the change in porosity is then measured, it will be found that conditions are much more complicated. The porosity of the final product will be found to depend not only on the size of the spherical grain, but also on its resistance to deformation, and on its surface condition. Even if it were feasible to select from one batch of powder manufactured by any particular method, a number of very small grains of equal size and a number of coarse grains likewise of equal size, it could hardly be reasonable to assume that such different powders would possess identical physico-chemical properties. If one grain has been reduced to smaller size than another, there must be some cause for this, and whatever the special conditions are, their influences will continue to operate. With regard to cohesion, Jones has pointed out that far from being overcome, the intensity of its effect may actually increase. But apart from these considerations, actually one will never have to deal with particles of equal size; and it need hardly be added that for the final density or porosity of a pressed compact, the relative grain size distribution is decidedly of greater importance than the absolute grain size.

That part of Balshin's work reviewed here, is in the main directed towards presenting a physical picture of the pressing process and rendering a mathematical representation of the results obtained from a large number of tests made. In general, Balshin's conclusions are based upon the study of pressing diagrams obtained with a press specially suited for test purposes. Care was taken to eliminate such sources of error, as deformation of the mould under the compression load, etc. An interesting feature of Balshin's test proceedure is the use of thin graphite powder layers between thin metallic sheets placed in the compressed powder. By this means, which represents a modification of V. S. Rakowski's original suggestion,‡ it was found possible to study the density distribution throughout the pressed piece with a fair degree of accuracy.

The Fundamentals of a Mathematical Formulation of the Pressing Process

In the pressing process, the pressure exerted by the plunger upon the contents of the mould, that is, upon the powder, performs a certain amount of work by compressing the powder contained in the mould. This expenditure of energy can be said to be the sum total of the following items:

1. Energy consumed in overcoming the cohesive forces acting between the powder particles, which forces must be overcome in the process of changing the position of the particles.

2. Energy consumed in the deformation of the particles and, as is often the case, in the combining of groups of particles into conglomerates.

3. Energy expended upon overcoming the elastic forces and residual stresses present in the conglomerate.

It is clear that the pressure requirements increase with increasing density of the pressed piece. The maximum pressure required for achieving final compactness, depends upon the following factors, to wit:

I. The actual forces of cohesion increase with two factors: (*a*) Increase in contact surface between the particles, and (*b*) decrease in the contact distance between the particles. Owing to these two factors, the cohesive forces increase with increasing compression.

II. The consolidation of the metal brought about by the augmentation of the compression, makes the deformation of the particles more difficult. Tearing of the particles from each other, can be accomplished only by increasing the pressure to a point where the cohesive forces acting between the particles are overcome.

III. The compression effort increases with increasing density.

In order to analyse the variations in pressure which occur during the pressing process, one may assume a cylindrical layer of powder of a height h, subjected in the mould to the specific pressure p (kg./cm.^{2}). As indicated

* M. Y. Balshin, "Contribution to the Theory of Metalceramic Processes," *Vestnik Metallopromishlenosti* (in Russian). Vol. 18, p. 124-137.

‡ V. S. Rakowski. "Fundamental Considerations in the Production of Hard Alloys" (in Russian), a book; Onti, Moscow, 1935.

in Fig. 1, an increase in pressure by an infinitely small amount dp, will cause a corresponding decrease in height dh. The work of compression per unit area of the cylinder cross-section is expressed by $dw = -p\,dh$. If it is assumed that the increase in pressure dp takes place in straight proportion with the work of compression, the following equation can be established :

(1) $dp = -i\,p\,dh$,

where i is a factor of proportionality. In general, this factor i is not, however, a constant, but is a function of the condition of the pressing process. This is expressed by

(2) $i = f$ (a, b, c, d, . . . p),

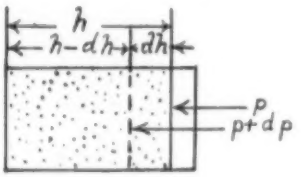


Fig. 1.

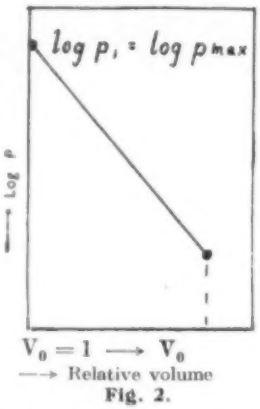


Fig. 2.

where a, b, c, d, etc., are factors which remain constant during the course of the pressing process, that is, such factors as kind of metal, speed of pressing, temperature, dimensions and shape of the pressed piece, and also size and shape of the particles of which the powder is composed in its original state. But it should be noted that during the pressing process, both shape and size of the particles are subject to variations. It is, however, claimed by Balshin that the factor i is mainly a function of the initial conditions prevailing at the commencement of the pressing process.

Equation (1) suffers from the disadvantage that the factor i is by no means independent of the quantity of powder in the mould. As a matter of fact, if the mould volume is increased tenfold, the coefficient i will also increase approximately tenfold. For this reason it is preferable to base formula (1) on the relative change in height rather than upon the absolute change. Introducing h_k as the height of the piece in compact state equation (1) can be written as follows :

3. $dp/p = -1\,dh/h_k = -1\,d\frac{h}{h_k}$, where 1 is a coefficient equalling $1 = h_k \cdot i$
$= h_k \cdot f$ (a, b, c, d . . . p)
$= F \cdot$(a, b, c, d . . . p)

As the cross-sectional area of the pressed cylinder is constant, it is $h/h_k = v/v_k = V_0$, where v is the volume of the pressing mould, v_k is the volume of the material of the pressed piece in compact state, and V_0 is the relative volume of the mould. It is therefore :

3a. $dp/p = -1\,(dv/v_k) = -1\,d\frac{v}{v_k} = -1 \cdot dV_0$

Balshin considers it permissible to assume that within certain pressure and deformation limits 1 remains constant. He also points to the similarity which exists between equation (3) and the equation expressing Hooke's law. The latter can be written in the form

5. $dp = E \cdot dh/h_0$,

where E can be assumed to remain constant within certain limits. There is, however, a fundamental difference between the equations (3) and (5) insofar as equation (5) shows the extent to which the loading dp varies with the deformation, while equation (3) indicates the change in dp/p with increased load. It will be remembered that Hooke's law is applicable only within a limited range of deformation, and even so it yields approximate values only. In analogy with this, the coefficient 1 applying to the pressing process, remains constant only within a limited range. Balshin states, however, that his equations of the pressing process, can be used for all practical purposes with sufficient accuracy, their applicability extending to the majority of powders used in practice and to all pressures used for practical purposes (14,000 to 70,000lb.). And this applies also to non-metallic powders.

By integrating the differential equation (3a) between the limits V_{01} and V_0, and assuming 1 to remain constant, it is :

$$\int_{p'}^{p} \frac{dp}{p} = -\int_{V_{01}}^{V_0} 1\,dV_0 \text{ or (6) : } \ln p - \ln p' = 1\,(V_0 - V_{01})$$

On the base of Brigg's logarithms, the latter equation changes into

$\log p - \log p' = \log e \cdot 1 \cdot (V_0 - V_{01})$, or

$\log p - \log p' = -L\,(V_0 - V_{01})$ (7), where $L = \log e \cdot 1$, and $L = 0{\cdot}434 \cdot 1 = 0{\cdot}434 \cdot F \cdot$(a, b, c, d, . . . p) (8). Equation (7) can, of course, also be written :

$\log \frac{p}{p'} = -L\,(V_0 - V_{01})$ (7a), or

$\log p = -L \cdot V_0 + C$ (9), where C is the constant of integration expressed by

$C = L \cdot V_0 + \log p'$.

In analogy with the term "modulus of elasticity" in Hooke's law, Balshin terms the factor L the "modulus of pressing." The Physical meaning of this modulus of pressing becomes clear if it is written in the form

$$L = \log \frac{p}{p'} / -(V_0 - V_{01}) = \log \frac{p}{p'} / -\Delta V_0 \quad (10).$$

and if $\Delta V_0 = -1$. The modulus of pressing can be defined as a measure indicating the increase in pressure incurred with a decrease in the relative volume of the pressed piece. In itself the pressing modulus is an abstract number. Balshin calls the reciprocal of the pressing modulus the "coefficient of deformability" indicating the specific decrease of the volume of the pressed piece with a tenfold increase in pressure. While the modulus of elasticity in Hooke's law does not depend upon the structure of the material, the modulus of pressing changes considerably with the structure of the original powder and, of course, also with its chemical constitution. But other factors such as size and shape of the pressed piece, speed of pressing, etc., have a much smaller influence upon the magnitude of the pressing modulus.

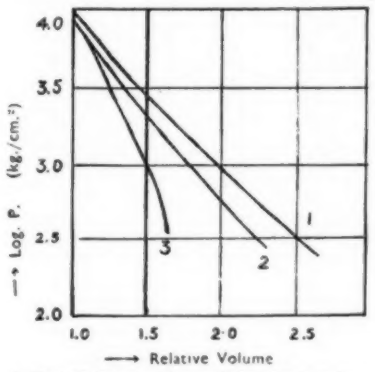
As the differential equations (1) and (3a) show, a decrease in height and volume in linear progression is accompanied by a pressure increase taking place in geometric progression. As Fig. 2 illustrates, the theoretical relationship between relative volume and the logarithm of the pressure as expressed by equation (7), follows a straight line law. In reality, however, the V_0 versus log p diagrams as obtained by test, deviate from this straight line relationship. As Balshin explains, this is due to changes which the original properties of the powder are undergoing during the course of pressing. It is interesting to note that according to Blashin, the coefficient of deformability and the pressing modulus are applicable not only to individual particles, but also to conglomerates.

The Influence of the Original State of the Powder upon the Pressing Diagram

The influence of the degree of dispersion. In the pressing process, the behaviour of a conglomerate of particles depends upon the magnitude of the forces acting present in the interior of the particles themselves. The inter-particle forces are, of course, represented by the forces of inter-particle cohesion which must be overcome by the compressing force. Although the compression of powders may lead to a greater equilibrium of state in compressed condition than that prevailing in the uncompressed state, an expenditure of energy in the act of compression is required for destroying the original distance equilibrium.

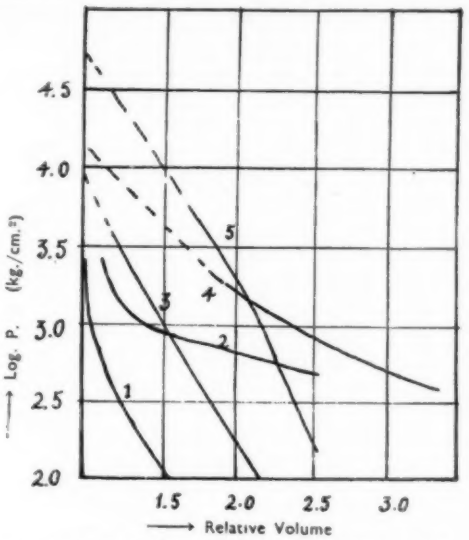
In the initial stages of pressing, the pressure exerted upon the powder is expended mainly upon overcoming the cohesive forces in order to achieve shifting of the particles from their original positions. A small amount of pressure is also expended upon the work of deformation. Considering the fact that the magnitude of the cohesive forces increases with the degree of dispersion, it is easily seen that for the pressing of fine powders, a much larger initial pressure is required than for coarse ones. In the last stage of the pressing process, the interval forces begin to play an important role, and the compressive forces are employed for filling out remaining voids by way of deformation of the particles without, however, breaking the contact between adjacent particles. It is obvious that this deformation is more easily achieved with small particles than with large ones, since the fine material flows with greater ease into the small voids.

The capacity of a powder to deform is, however, expressed by the coefficient of deformability $1/L$;



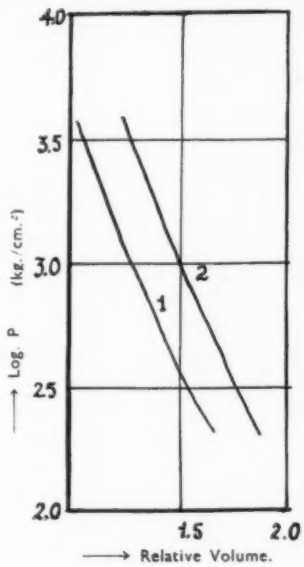
1. Electrolytic copper, fine particles, when loosely heaped : 0·97 grms./cm.³
2. Electrolytic copper, medium fine particles, when loosely heaped : 1·5 grms./cm.³
3. Granulated coarse copper particles, of spherical shape, when loosely heaped : 4·5 grms./cm.³

Fig. 3.



1. Lead, pulverised coarse, when loosely heaped, 3·98 grms./cm.³
2. Electrolytic tin, fine, when loosely heaped, 1·1 grms./cm.³
3. Electrolytic iron, coarse, when loosely heaped, 2·7 grms./cm.³
4. Iron, fine, when loosely heaped, 0·51 grms./cm.³
5. Tungsten, when loosely heaped, 4·18 grms./cm.³

Fig. 4.



1. Graphite.
2. Anhydrous soda.

Fig. 5.

large values of this coefficient indicate a high degree of deformability, and vice versa. Therefore, the pressing modulus (represented by the tangent of the angle of inclination of the pressing characteristic with the abscissa) is greater in the case of coarse powders; and, in spite of the fact that the intitial pressure requirements may be smaller, the final pressure (for identical density) required with coarse powders can thus be greater than that called for in the case of fine powders. This fact is exemplified by the three curves charted in Fig. 3.

There is another interesting aspect of the relationship between the modulus L and the degree of dispersion. It was already mentioned that this modulus is influenced by changes of the powder from its initial state as expressed by its degree of dispersion, shape and structure of the particles, etc. Obviously, fine powders offer a greater surface area, and a higher degree of deformability must therefore be expected of them. But at the same time, initial fineness is particularly liable to variation during the pressing process. For this reason it must be expected that a change in the magnitude of the modulus L during the pressing process will be due to the coarsening of the powder taking place during the process of compression. This explains why the pressing diagrams of disperse powders deviate considerably from the linear characteristic and show a pronounced curvature, with the hollow side of the curve facing the abscissa. In contrast to this, originally coarse powders do not show any great change from the original state, and their pressing curves do not therefore deviate much from the straight-line characteristic. As a matter of fact, it sometimes happens with coarse powders that L decreases in the course of the pressing process with the result that the pressing characteristic curves in the opposite manner. Balshin adds that, to a certain extent, this phenomenon may be due to a possible increase in the state of dispersion and thus in specific surface, which increase may be due to the formation of fissures or due to a mutual grinding effect.

The Influence of Particle Shape.—It is clear that smooth particles find their place more easily than rough ones, and the initial pressure requirements in the case of powders composed of smooth particles are therefore smaller than those to be applied to powders consisting of rough particles. However, the deformability of smooth powders is less than that of rough ones, and the modulus of smooth powders is therefore greater. Consequently, smooth powders tend to have a characteristic which deviates less from the straight line relationship than that found with rough powders. In view of the infinite variety of particle shapes, it is, of course, quite impossible to enter into a discussion of the relationship between the various shapes and the pressing characteristic. But it may be mentioned that spherical particles which possess a minimum surface per unit weight, will always show a surface increase if deformed. In their case it is therefore possible that the modulus L decreases in magnitude as pressing proceeds.

The Influence of the Composition of the Powder. Hard metals naturally possess a smaller deformability than soft ones, and one can formulate the following fundamental facts :

1. Hard metals require greater initial and final pressure than soft metal of the same relative density.

2. The importance of the modulus L is greater with hard metals (based on identical relative density and structure.

3. In the case of hard metals, the pressing characteristic shows less tendency to deviate from the straight line characteristic of the ideal V_0 versus log p diagram. With soft metals, the modulus L usually increases with the compression, while the opposite tendency may be found with hard metals.

But these influences may again be overshadowed by other factors originating from the degree of dispersion and from the shape of the individual particles. Thus, a fine copper powder may require a higher pressure than coarse iron, but the modulus L of the copper powder may be smaller than that of the iron powder. Facts of this kind may serve to emphasise the first-class importance

of the structural factors in the problems of powder metallurgy.

With regard to non-metallic powders, of which two typical pressing characteristics are given in Fig. 5, it may be noted that in comparison to metallic ones, such powders are characterised by their small cohesive forces between the particles and by their small deformability. With non-metallic powders, the initial pressure requirements are therefore relatively smaller, the modulus L is greater, and the deviation of their characteristics from the straight-line law is nearly always smaller than in the case of metal powders. There may, however, be exceptions from this rule.

There exist also many other factors, in addition to those mentioned above, which are of influence upon the compressibility of a powder. Thus structural subdivisibility of the particles and tendency towards consolidation under the influence of the compressive force are both conducive to a decrease in deformability and to an increase in the magnitude of the pressing modulus L. From what has been said before, it will be readily appreciated that while constituting an important means for the theoretical analysis of the pressing process, the $V_\theta = \log p$ diagram also greatly facilitates the control and analysis of the powder as such. On the basis of this diagram, it is possible to establish the graphic relationship between the modulus L and V_θ or p.

(To be continued.)

Corrosion Fatigue of Notched Cast-Iron Specimens

Results are given of some recent corrosion-fatigue experiments on un-notched and notched specimens of cast iron.

EXPERIMENTS have shown that soft grey cast irons are immune to notch effects in fatigue as specimens of those irons with a square notch, a V-notch or one with a hole bored through it, show endurance properties the same as those of a smoothly-filleted bar of the same cross-section. This is in sharp distinction to the notch sensitivity in fatigue of steels, which is high, even in a soft steel, and increases so rapidly as the tensile strength of the steel is increased that, for use under repeated stress where stress concentration is not avoided, the increased fatigue resistance that is shown on a smooth filleted bar is nearly or entirely nullified. A strong steel may therefore be worse in notched fatigue than a medium strength steel, and a medium-strength steel only a little better than a very weak one.

As cast iron is increased in strength, it shows some notch sensitivity till, in a high-duty cast iron, the notch sensitivity approaches that of a soft steel, and some of the value of high endurance on a filleted bar is cancelled. As a result, it has been suggested that somewhere intermediate between very soft and very strong cast irons there should be a class in which the fatigue strength would be relatively high and the notch sensitivity relatively low. A cast iron of this type would have an engineering value for use under repeated stresses where notches cannot be avoided.

It has also been shown that corrosion prior to repeated stress produces pits and roughness whose effects are analogous to mechanically-formed notches. In steels which are not thoroughly corrosion resistant, corrosion simultaneous with repeated stress nullifies, even more effectively than does a pre-formed notch, the value of strength, so that in corrosion fatigue of ordinary non-corrosion resistant steels, strength is of practically no importance. In this respect also hard steels behave similarly to soft steels. In view, however, of the notched fatigue resistance of cast iron, the question arises as to whether cast iron is also resistant to the effects of corrosion fatigue. Corrosion of cast iron prior to fatigue testing shows such corrosion to reduce the endurance value of the material. Data on simultaneous corrosion-fatigue of cast iron are very scarce, because cast iron is not ordinarily thought of as a corrosion-resistant material. Recent corrosion-fatigue experiments by H. W. Russell and J. G. Lowther on un-notched and notched specimens of cast iron are therefore of interest.

Un-notched rotating beam fatigue specimens of an iron containing 3·03% carbon, 1·43% silicon, 0·47% manganese, 0·09% sulphur, and 0·17% phosphorus, having a tensile strength of 23·2 tons per sq. in., and a Brinell hardness of 230 were run in tap water at 1,785 r.p.m., and 17,000, 16,000, and 14,000 lb. per sq. in. The specimen loaded at 17,000 lb. per sq. in. failed at 5½ million cycles, the one loaded at 16,000 lb. per sq. in failed at 21½ million cycles, and the one loaded at 14,000 lb. per sq. in. ran 55 million cycles without failure. Two other cast irons were similarly tested on unnotched bars with the following results:

TABLE I.

C.	Si.	Mn.	S.	P.	Tensile Strength. Tons per Sq. In.	Brinell Hardness.	Stress in lbs. per Sq. In. for 10 Million Cycles.
3·04	2·29	1·04	0·065	0·12	12·9	172	7,500 Approx.
3·00	1·75	1·16	0·073	0·06	18·7	209	11,500 „

A commercial, cupola melted, iron containing 3·42% carbon, 1·49% silicon, 0·75% manganese, 0·10% sulphur, and 0·23% phosphorus, having a tensile strength 17·9 tons per sq. in. and a Brinell hardness of 213 was tested both in the unnotched and notched conditions. The endurance limits for air for 10 million cycles were 17,500 lb. and 15,000 lb. per sq. in. unnotched and notched, respectively. Under corrosion fatigue in tap water, at about 1,800 revs. per min. the stress for a life of 10 million cycles was: unnotched 13,000 lb. per sq. in., notched 13,000 lb. per sq. in. This value of 13,000 lb. per sq. in. was somewhat similar to the value obtained for corrosion fatigue of a heat-treated nickel-chromium steel, and indicated that high-strength cast irons might not be much inferior to steel under corrosion fatigue in the presence of external stress raisers.

With regard to the results obtained from the various irons it might be noted that the corrosion fatigue value of the 18·7 tons per sq. in. iron, containing 0·06% phosphorus, was not so good as that of the 17·9 tons per sq. in. iron containing 0·23% phosphorus or of the 23·2 tons per sq. in. iron containing 0·17% phosphorus. The tests, however, are insufficient to prove that phosphorus is a factor in the corrosion fatigue of cast iron, but the possibility that it is exists.

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The Formation and Properties of Martensite on the Surface of Rope Wire*

By E. M. Trent, M.Met., Ph.D.

The occurrence of thin layers of martensite on the worn surfaces of wires in wire ropes used in mining is described. These layers are very easily cracked, and the cracks lead to a rapid failure of the wires through fatigue. This produces a very dangerous form of deterioration, particularly in mining haulage ropes. This report gives the results of an investigation carried out as part of the work of the Safety in Mines Research Board on Wire Ropes, on the occurrence and effect of these thin layers. It is to be presented at the forthcoming annual meeting of the Iron and Steel Institute.

[SLIGHTLY ABRIDGED]

WIRE ropes used in mining, in particular haulage ropes, are frequently subject to severe wear in service. This wear, by reducing the cross-sectional area of the outer wires, gradually reduces the strength of the rope. A more serious effect where severe wear takes place is the formation of a brittle surface on the wire. Cracks are formed in this brittle surface, and these can lead to the rapid failure of the outer wires before they have been seriously reduced in cross-section. This type of deterioration is more difficult to detect by inspection, and is therefore more dangerous. In a recent case examined by the Safety in Mines Research Board a haulage rope failed after only six months' service. Examination on the day before failure had revealed no defect. Investigation after failure showed that the outer wires had been reduced in diameter by only 11%, while the general recommendation of the Safety in Mines Research Board with regard to wear is that a round strand rope becomes unsafe and "should not be allowed to remain in service after 40% of the thickness of the outer wires has been worn away at the worst point."

In this case the deterioration had been caused by the formation of a brittle layer on the worn surface. Examination of sections of the wires under the microscope showed the presence of a layer of martensite, of maximum thickness approximately 0·003 in. covering a large area of the worn surface. Cracks formed in this martensitic layer, which was very brittle, caused the failure of 20 out of the 36 outer wires in the rope at the point of fracture.

The presence of such martensitic layers, caused by a rapid heating and cooling of the immediate surface of the wires during friction, has been known for some time, but their importance as a factor in the deterioration of wire ropes has been underestimated. The following figures indicate the frequency with which martensite occurs and its importance as a cause of failure in mining haulage ropes. On the last 35 haulage rope breakages examined by the Safety in Mines Research Board, two were capel failures. Of the remaining 33, 24, or 72%, showed the presence of a layer or martensite on the worn surfaces, while in the case of 13 or 39%, the martensite was definitely an important contributory cause of failure. Because of its importance in this respect further investigations into the mechanism of the formation and the properties of the martensitic layers were carried out.

Structure of the Martensitic Layers

The area covered by any one layer of martensite on the worn surface is comparatively small and in the form of a narrow strip. This strip extends along the worn surface of the wire in the direction of rubbing, that is, in the direction of the axis of the rope. In the case of a lang-lay rope the strip extends diagonally across the worn surface of the wire. If the worn surface is polished and etched the strips of martensite show up white against a dark background. When the wire is sectioned through the worn surface, polished and etched in 1% nitric acid in alcohol, the martensite appears as a white or slightly yellow structureless layer sharply separated from the sorbite of the normal wire. This layer normally varies in thickness from approximately 0·0001 in. to 0·0035 in. In cross-section the strips are lenticular in shape, being thickest towards the centre and decreasing in thickness towards the sides, the total width of the strip being usually not more than 0·03 in. The small size of the martensitic areas indicates that the area of contact between the wire and the rubbing agent is very small, and thus the local pressure may be very high.

In many cases the wire surface has been subjected to friction a great many times. The layers of martensite thus formed frequently overlap. In some cases several layers of martensite are produced one on top of the other, the last layer formed in each case tempering the layer immediately preceding it, so that the layers are separated by dark bands.

The temperature gradient in the wire caused by the friction is undoubtedly very steep. A rough estimate of the steepness of this gradient can be made from the tempered layers, which are usually not more than 0·002 in. thick. Supposing that the minimum temperature required to form martensite is 700° C. and the minimum temperature to cause a visible darkening of the martensite is 400° C., then there is a temperature gradient of 150° C. per 0·001 in of the tempered martensite. It is possible that a higher temperature than 400° C. might be required to produce a visible darkening of the martensite, owing to the extremely short time of tempering, but the figure given above may be regarded as a rough estimate. It may be assumed that the temperature gradient is at least as steep in the martensite—*i.e.*, in that depth of the steel that was converted to austenite—so that in a layer of martensite 0·003 in. thick it is probable that the surface reached a temperature of at least 1,150° C.

The heating and cooling of the surface layer must take place in a very short space of time—a matter of a few seconds, if not less. The transformation, on heating from sorbite to austenite must proceed very rapidly, and this is facilitated by the fact that in rope wire the carbide is very finely dispersed. The structure of the sorbite is either not resolvable or only just resolvable at a magnification of 1,000 diameters. A coarser structure would require either a longer time or a higher temperature for the complete transformation to austenite. Where there are ferrite streaks at the grain boundaries of the steel these are frequently not dissolved into the austenite on heating, and are visible in the martensite. This is probably due to the fact that, although they are thin, these streaks of ferrite are many times thicker than the cementite laminæ of the sorbite, and hence would take longer to dissolve. The very rapid cooling of the surface layer is due to the continuous contact of the very thin heated layer with the

* Iron and Steel Institute, 1941, Annual General Meeting. (Advance copy.)

main body of the wire, which remains cold; the cooling is mainly due to conduction through the wire.

The martensite etches either white or slightly yellow in colour, depending on the time of etching, but no acicular structure is developed, probably because of the extremely small grain size produced by the rapid heating and cooling. When a layer of martensite is subjected to a second period of friction, the very small grain size and the even finer distribution of the carbide again facilitate its rapid transformation to austenite, while the martensite which is reheated to a temperature below the critical point is tempered, with the precipitation of very finely dispersed carbide particles. This finely dispersed carbide etches very rapidly in 1% nitric acid in alcohol, quickly becoming jet black.

So far, only martensitic layers formed from the steel of the wire itself have been considered. This is the main cause of surface brittleness in wires from haulage ropes. If the worn surfaces of the wires are examined at a low magnification they are frequently seen to be rough, as if there had been actual seizing of the wire on to the object against which it was rubbing. If a wire is sectioned through these rough areas, the extreme outer layer of the martensite is by no means homogeneous. At least a part of this material is apparently iron or steel which has welded on to the wire from the surface against which the wire was rubbing under conditions of high pressure and temperature. These welded-on layers are usually extremely thin in haulage ropes (less than 0·0005 in.), and for this reason the structures are difficult to interpret.

On the worn surfaces of two winding ropes, much heavier layers of extraneous material were found welded on to the wire. In one of these the extraneous material consisted of ferrite with numerous slag particles, welded on to a partially-tempered layer of martensite formed from the steel of the wire. The welded-on material is probably either wrought iron or the surface layers of a weld. In the second case, the welded-on material was obviously a mild steel. It had been welded on to the wire from a mild-steel plug in a capel, against which the wire seized when the rope failed at the capel. Examination of the plug showed that its surface layers also had been heated to a high temperature and that thin flakes of martensitic steel (0·0005 in. thick) from the wire had been welded on to the plug in some places.

It is thus demonstrated that, under the conditions of friction found in service, the rope can seize or weld locally on to the object against which it is rubbing. When such welding takes place the welded materials subsequently break apart, either (*a*) at the weld, or (*b*) by tearing away portions of the wire or the other object. Which of these occurs depends on the strength of the weld (*i.e.*, on the temperature and pressure of welding, etc.), or on the strength of the two materials and the presence in them of cracks or other sources of weakness. In any case, this must lead to rapid wear of the object against which the rope is rubbing, and probably also of the rope itself. Where such seizing occurs the coefficient of friction will greatly increase, and consequently the heat generated will also be much greater and martensite is more likely to be formed.

The Cracking of Martensitic Layers

The thin layers of martensite on the surface of the wire are very brittle and can withstand very little, if any, plastic deformation. Thus, it is usual to find that the martensite produced on rope wires in service contains numerous cracks. An examination of the worn surfaces at a low magnification frequently reveals a whole series of cracks running across the wire. Once a crack is formed in the martensite it acts as a stress-raiser. The bending stress induced in the wire—for instance, when the rope passes over a pulley—is concentrated at the base of the crack, which is rapidly deepened by fatigue until the wire breaks. In wires that have been fractured by a single application of a bending stress at a cross-section containing an embrittled surface, it is frequently found that the fracture started from a crack in the worn surface and proceeded for a certain distance in shear. Thus a crack in a martensitic layer constitutes an important source of weakness in rope wire.

These cracks are most frequently found at or near a point where a layer of martensite has been reheated by the overlapping of a second layer. The stresses set up by the heavy pressure and friction and those caused by the steep temperature gradients involved are probably the cause of the cracking of the martensite in most cases. It is possible that the pressure of the rope on the object against which it is rubbing, by causing a local bending of the wire, would itself be sufficient to propagate the cracks into the sorbite. Thus, sufficiently high rubbing stresses may, by themselves, cause failure, even though the actual loading stresses on the rope are safe and the pulley diameters sufficiently large.

The cracks found in martensite are not always normal to the wire surface, but often are bent over. This bending over of the crack is possible because, during the time of friction, the martensitic layer of the metal would be austenitic at a temperature of over 700° C., and hence would be highly plastic.

Experimental Work: Laboratory Production of Martensitic Layers

Preliminary experiments suggested the possibility of reproducing in the laboratory the martensitic layers on the wire surface by striking the wire a glancing blow.

The wire used for these experiments was of "plough steel" grade—a grade of hard-drawn, sorbitic wire of a type used for wire ropes. The wire was 0·1 in. in diameter, with a tensile strength of 109 tons per sq. in. In the reverse bend test over a 5-mm. radius it required nine or 10 bends through 180° to fracture it. The number of twists to failure in the torsion test was 41 over a length of 100 diameters. The composition of the wire was as follows:

0·61% 0·70% 0·112% 0·035% 0·042%

An attachment was made by which a hardened steel tool, rounded at the end, was fastened to the pendulum of an Izod impact testing machine. The wire was held by means of a special grip in the vice of the machine; the axis of the wire was in the plane of swing of the pendulum and the wire was slightly bowed. The tool thus struck the wire a glancing blow and the energy absorbed was measured in foot-pounds on the scale of the Izod machine. It was found that when the energy absorbed was below 8 ft. lb. no martensite was formed, and the surface was merely scored. When the tool was lowered so that a deeper "cut" was taken, the wire very little scored and a layer of martensite was formed, which increased in thickness as the energy absorbed increased.

The tool was deeply nicked by the blow, and that part of the wire on which martensite was found had increased in diameter by 0·001 in. This suggested that material from the tool had been welded on to the wire. This was confirmed by weighing the tool and the wire before and after the operation. The wire gained 0·0021 g. in weght, while the tool lost 0·0039 g. on the average.

Micro-examination revealed two layers in the martensite, the outer layer being formed from the tool, and the inner one from the steel of the wire itself The inner layer consisted of the normal slightly yellow-coloured martensite. The outer layer was much whiter, but had brown irregular markings running vertically through it. It was found that where the outer layer was cold-worked after the formation of martensite, as, for instance, where the wire was cut with clippers, the brown markings became an interlacing network of lines, and the whole of the outer layer etched a yellow-brown colour. Several of the wires were tested for fatigue, and one showed a fatigue crack starting from the martensite. Where the fatigue crack passes through

the outer layer, this layer has been cold-worked, and the brown markings have become a mass of interlacing lines. Under high magnification these brown markings are seen to be a series of very fine needles. This microscopical evidence indicates that the majority of the outer layer at first consisted of austenite (which etched white), with a few series of needles of martensite. The application of cold-work rapidly converted this austenite to martenite. The tool from which the austenitic layer was formed was made from a plain carbon tool steel containing approximately 1·2% of carbon. The retention of so much austenite in a plain carbon steel is most unusual and must have been caused by the exceptionally rapid cooling of this very thin layer.

The structures produced very closely resemble the structures found in the outer layers of martensite on some rope wires from service.

Properties of the Martensitic Layers

The martensitic layers produced in the laboratory were easily cracked by bending the wire through a small angle, *e.g.*, through an angle of 20° over a radius of approximately ½ in. In the reverse-bend test over a 5-mm. radius, a wire with martensite on the surface broke after seven bends, while a wire without martensite withstood nine or 10 bends. In this severe test the fracture was propagated mainly by shear, with large tears accompanying each bend to produce a very rough fracture. Cracks were also produced by 12 bends through approximately 20° over a 5-mm. radius. With this small angle of bend the cracks produced were much more smooth and more like fatigue cracks, the amount of tearing accompanying each bend being much smaller. Under these conditions a wire with a layer of martensite contained a crack penetrating to one-third of the diameter after 12 bends, while a wire without martensite required 45 bends to produce the same result.

It has not been possible to carry out a full series of fatigue tests for the comparison of wires with and without martensitic coatings. This is because, in producing the martensitic coating, the tool slightly nicks the wire at the point where it first comes in contact with the wire. The wires tend to fail at this damaged part, and thus the results of the fatigue tests cannot be regarded as demonstrating conclusively the effects of martensite on the fatigue properties of the wire. The results, however, indicate that a martensite coating, starting without cracks, has little influence on the fatigue limit or on the number of reversals to failure up to a stress of approximately 45 tons per sq. in. This might be expected, since the tensile strength of martensite is certainly not lower than that of the sorbite of the drawn wire. However, if the martensite were cracked before the test it would be expected that the fatigue limit would be greatly lowered, since these cracks would act as stress raisers. Also, if the reversed stress were raised to a point where the plastic deformation of the wire itself was comparatively large, the martensite, being unable to deform plastically, would be cracked during the first few reversals of stress, and the wire would fail rapidly. Thus, one would expect that when the stress was raised above a certain point the wires with a martensitic coating would prove themselves markedly inferior to the normal wire. Such a tendency is indicated by the result of the reverse-bend test through a small angle described above.

The martensitic coating appeared to have little effect on the tensile strength or on the torsion-test results.

The above method of forming martensite by means of a rapid glancing blow probably does not correspond closely to the conditions under which it is formed in rope wire; here the martensite is formed by a slower friction with heavy pressure. In order to reproduce these conditions a wire was fixed to the travelling table of a planing machine, and was worn by lowering on to it a tool with a rounded end. At first a tool tipped with a polished piece of tungsten carbide was used. The wire was very rapidly worn, a polished surface being produced, while the tool itself was not marked. The worn surface, however, was not excessively brittle, and no martensite could be detected under the microscope. A layer of martensite was produced, however, by first wearing the wire with a tungsten-carbide tool to produce a flat surface, and then wearing it with a hardened-steel tool, which tore and roughened the surface to some extent, although the tool itself was hardly marked. From the appearance of the wire and the tool it seems that some seizing took place, which did not occur with the tungsten carbide tool. The speed of travel of the wire relative to the tool was approximately 0·4 ft. per sec., which is less than one-tenth of the maximum speed of a haulage rope in service.

Discussion

The work of Bowden and his co-workers[1 2] has shown that during friction there is a considerable rise in temperature at the interface. For pairs of metals such as lead and steel, Wood's metal and steel, constantan and steel, etc., it was found that the surface temperature achieved was directly proportional to the relative velocity of the two surfaces and to the load, until the melting point of the lower-melting metal was reached, after which no increase in surface temperature occurred. It was also found that in most cases the sliding of one metal over the other took place in jerks, the surfaces sticking together, then slipping a short distance, then sticking again. The coefficient of friction was found to attain very high values when two similar metals were rubbed together, and in this case seizing readily occurred, and both surfaces were torn.

The present work on martensite is in agreement with these results. Since the pressures associated with the wear of haulage ropes are much greater than those used by Bowden, one would expect to find higher surface temperatures than those recorded in his work; also the depth of the high-temperature zone is much greater. The seizing of the wire with the object against which it was rubbing is also in agreement with the process of sliding as described by Bowden, but, once again, the pressure being much higher, the actual area of seizing or welding-together, is probably considerably greater.

Since the quantity of heat liberated during friction is proportional to the coefficient of friction, and since the coefficient of friction is highest for two similar metals, one would expect martensite to be formed most readily when steel rubbed against steel. As described above, when a wire was rubbed with a tungsten-carbide tool no visible layer of martensite was formed, while a heavy layer was produced with a hardened carbon-steel tool. The higher coefficient of friction and the higher surface temperatures attained between two similar metals are undoubtedly associated with the fact that seizure and welding would occur more readily between two similar than between two dissimilar metals.

A Note on Corrosion Pitting on Worn Surfaces of Haulage Ropes

A distinctive form of corrosion pitting is sometimes found on the worn surfaces of haulage ropes. This takes the form of chains of pits running down the centre of the worn surface. It was noticed that this pitting was frequently associated with the presence of martensite. Examination of the pitted surface at low magnification after polishing and etching revealed in nearly every case layers of martensite on the unpitted part of the surface with cracks running into the pits. Micro-examination of sections through the pitted surface showed that in many cases the corrosion pits undermined the martensitic surface. This suggested that the pitting might be caused by a localisation of corrosion at the cracks in the martensite. It is difficult to prove this by the examination of pitted wires, since the process of pitting proceeds simultaneously with the

1 F. P. Bowden and K. E. W. Ridler: *Proceedings of the Royal Society*, 1936, vol 154, pp. 640-656.
2 F. P. Bowden and D. Tabor: *Proceedings of the Royal Society*, 1939, vol. 169, p. 391.

processes of wear and martensite formation, so that evidence of the original cracks from which the pits were formed is destroyed in the process. However, the presence of cracks and the undermining of the martensite by corrosion indicate the probability that this is the cause of pitting.

An attempt was made to reproduce this pitting in the laboratory. Wires coated with martensite by striking a glancing blow, as described above, were bent so as to crack the martensite. The wires were then immersed in a 1% solution of sulphuric acid for various periods of time at room temperature (approximately 20° C.). After 6 hr. small areas of the martensite between the cracks began to flake off, being completely undermined by corrosion. After 14 hours comparatively large areas of martensite had flaked off, exposing corrosion pits of considerable depth.

Although these tests deal only with one corrosive medium, they show that corrosion pits can be formed owing to cracks in the martensitic surface. This pitting may be due either to an electro-chemical effect caused by a difference in potential between the martensite and the sorbite (enhanced in this case by the fact that the outer layer of the martensite was of a different composition from that of the wire itself), or to differential æration, causing localisation of corrosion at the base of the crack. In the latter case it would be expected that corrosion would occur at any crack in the steel, whether martensite were present or not. There is some indication that this may be so, but in any case the importance of martensite in causing pitting is not diminished, since the presence of martensite seems to be the main cause of cracking of the worn surface.

Conclusions

1. The formation of martensite on rope wire is an important cause of deterioration and failure in haulage ropes, and can also contribute to the deterioration of winding ropes.

2. The presence of martensite on the worn surface of the wires may lead to rapid failure of the rope by fatigue before inspection reveals that the rope is in a dangerous condition. Care should be taken to prevent the rope from rubbing against any metal object, such as seized pulleys or rollers, rails, steel sleepers, roof girders, etc.

3. In rubbing against such objects the rope wire may seize on to them, and this leads to the rapid wear both of the rope and of the object against which it is rubbing. Thin layers of metal may be welded on to the rope wire, owing to the high pressures and temperatures during friction, and microscopical examination may be able to give an indication of the nature of the material against which the rope was rubbing.

4. Under certain conditions of corrosion the presence of martensite containing cracks leads to the formation of corrosion pits on the worn surface of wire. When these pits take the form of "chain pitting" they indicate that martensite is probably present.

Erratum

Mr. A. Butterworth has drawn our attention to a typographical error in his contribution on the subject of "The British Machine Tool Industry—Its Future." In the second complete paragraph in the right-hand column on page 143 of the last issue, the word "divided" in the fourth line should be "decided." The corrected paragraph should therefore read:—

"Whatever type of British machine tool which will give more economical production than the alternative foreign machine tool, should be produced here in larger quantities, the extra amount of production to be decided after a frank discussion, between the machine-tool makers concerned and the Machine Tool Controller, without interference or delay by the Treasury. Not only would this save "exchange" and "shipping space," but would increase the number of British machine tools as compared with foreign machines.

Complex Copper-Cobalt-Silicide Alloys

THE use of cobalt silicide as an age-hardening ingredient in copper has resulted in an alloy which in the wrought condition has rather unusual properties both electrical and physical. Recently, experiments have been carried out by F. R. Hensel, E. I. Larsen, and E. F. Holt,* on two copper-cobalt-silicide alloys, to which were added beryllium in the one case, and phosphorus in the other, in order to investigate the combined effects of cobalt silicide and cobalt beryllide, and cobalt silicide and cobalt phosphide.

The test material for the two alloys, whose compositions are given in Table I was in the form of 1-in. diameter rod selected from production runs and processed by hot rolling, and drawing. The age-hardening behaviour of the alloys as a function of both quenching and ageing temperatures was determined by the following sequence of treatments given to both alloys: (*a*) Water quenched from 900°, 950°, and 1,000° C.; (*b*) cold-worked various percentages after quenching; and (*c*) aged at temperatures of 400° 450°, and 500° C. for various time intervals.

TABLE I.

	A. %	B. %
Copper	96·44	96·03
Cobalt	2·66	2·69
Silicon	0·33	0·40
Cadmium	0·08	0·53
Iron	0·04	0·06
Beryllium	0·43	—
Phosphorus	—	0·31

Hardness/ageing-time curves plotted from the results of these treatments showed that ageing at temperatures in the vicinity of 500° C. increased the hardness. Ageing tests made on specimens cold worked various degrees from 0% to 50% reduction and quenched from 900°, 950° and 1,000° C., showed in general that the rate of hardness increase during ageing was in direct relationship to the amount of cold reduction prior to ageing. The alloys were also found to have quite a high rate of cold-working, the maximum hardness after ageing was obtained after quenching at a reduction of 20%, and was 105 Rockwell B for alloy A, and 97 Rockwell B for alloy B.

The electrical conductivity was determined on the alloys after quenching from 950° C., cold working by swaging and ageing at 450° C. There was little change in the conductivity with the amount of cold work, but ageing up to 32 hours resulted in a considerable increase in conductivity, an increase which appeared likely to continue with further ageing.

In the manufacture of the alloys it was found necessary to anneal the metal at different stages of processing. Annealing curves determined for both alloys, showed that if the annealing temperature of alloy A exceeded 900° C. the material hardened during air cooling, and in alloy B this hardening was found to take place at an annealing temperature of 900° C., with a subsequent air cooling. Alloy A when quenched from temperatures of 900°, 950°, and 1,000° C., had Rockwell B hardness values of 33, 43, and 75, respectively. Annealing during processing had therefore to be carried out at correct temperatures.

The subjection of the alloys during processing to high-temperature treatment in an oxidising atmosphere caused the formation of two definite oxide layers. The outer layers, which were quite brittle and could be readily removed, consisted primarily of Cu_2O with a small amount (2·5 to 3·0%) of cobalt. The sub-scale layer of alloy A was very tenacious, but could be detached by stressing and bending, whereas the sub-scale layer of alloy B, which was also very tenacious, could not be detached from the rolled samples. The formation of the sub-scale is extremely harmful, if the alloys are used in strip form for springs, because the intercrystalline penetration of the oxide reduces the fatigue limit very materially.

* *Metals and Alloys*, 1941, Vol. 13, No. 2, pp. 151-154.

High-Temperature Metallic Resistor Furnaces

High temperature metallic resistor furnaces were formerly limited in usefulness to laboratory experiments, but the recent development of materials and products requiring high temperature treatment has directed attention to the use of metallic resistors in furnaces large enough for plant practice. Furnaces are described in which the resisters are composed of molybdenum or tungsten, by which a temperature of 2,000° C. is attainable. Highly refractory oxides for making the cores are briefly described.

THE production of resistance materials for electric heating has involved much research work, and experimental investigations were in progress for many years with the object of overcoming difficulties which at one time were considered inseparable characteristics of these materials. Early attacks on the problem of developing suitable materials produced a succession of alloys from nickel silver to various steels, none of which was entirely successful until nickel-chromium alloys were developed for resistance heating. To-day, such alloys and their iron-containing modifications, by virtue of their peculiar suitability have been accepted as standard for heating element service. Iron base alloys of the iron-chromium-aluminium and iron-chromium-aluminium-cobalt types have also been developed. These alloys are higher in resistivity than the conventional nickel-chromium combinations; they have, in some cases, a lower temperature coefficient and are often more resistant to oxidation and scaling.

The most important properties of electric resistance alloys include resistance to oxidation and to scaling, and a comparatively high melting point with a narrow melting range. The resistor must not melt, nor commence to soften at the operating temperatures, and for practical purposes its working temperature should be at least 150° C. less than the melting point of the alloy used. For service at 1,150° C., therefore, the only suitable materials are those whose melting points exceed 1,300° C. This allows some service latitude, due to overheating, should fluctuation of the line voltage occur. The melting points of the nickel-chromium alloys and iron-chromium-aluminium alloys are relatively low, and their use in resister furnaces is normally limited to 1,200° C.

With the rapid development of various materials and products requiring high temperature treatment, there has been an increasing demand for furnaces suitable for commercial practice for which temperatures higher than the limits imposed on nickel-chromium and iron-chromium-aluminium alloys are necessary. The ability to resist attack by oxygen at high temperatures is an essential characteristic of resistance-heating alloys, unless, like the metals molybdenum and tungsten, they can be used in an inert or protective atmosphere of some kind. Adopting this method with the nickel-chromium or iron-chromium-aluminium alloys makes no appreciable difference to the operating temperature of the furnace in which they are used, because of their low melting points, thus attention has been directed to the development of molybdenum or tungsten resisters operating under a gas seal or in a vacuum, and furnaces equipped with resistors of this type are described by Kroll.*

Molybdenum and Tungsten Resistors

For the utilisation of molybdenum and tungsten resistors, knowledge of the specific behaviour of these metals is fundamental. Molybdenum sheet is generally furnished in the soft annealed state that will stand 30% elongation. If the sheet is not more than 0·5 mm. thick it can easily be bent sharply. Wires of molybdenum 1 mm. in diameter may also be bent cold to some extent. However, it is preferable to bend and shape them at dark red heat to avoid breaks in 45° bends, following crystal planes. Tungsten should in general be worked hot and held with pre-heated tongs. Tungsten sheet is extremely brittle in the cold (maximum elongation 1–3%) even in very thin sections. Both metals if heated to a temperature of, say, 2,000° C. become brittle, due to oxidation and grain growth. The presence of thorium in tungsten inhibits this embrittling to some extent. Even hydrogen containing only traces of water vapour will not protect tungsten at 2,000° C. On account of the embrittling effect of oxygen or air, the ends of the molybdenum or tungsten wires extending outside of the furnace are doubled up or covered with a tight-fitting sleeve of pure copper. In the latter case copper is melted in a high-frequency furnace employing a graphite mould. After melting and superheating the copper, the tungsten or

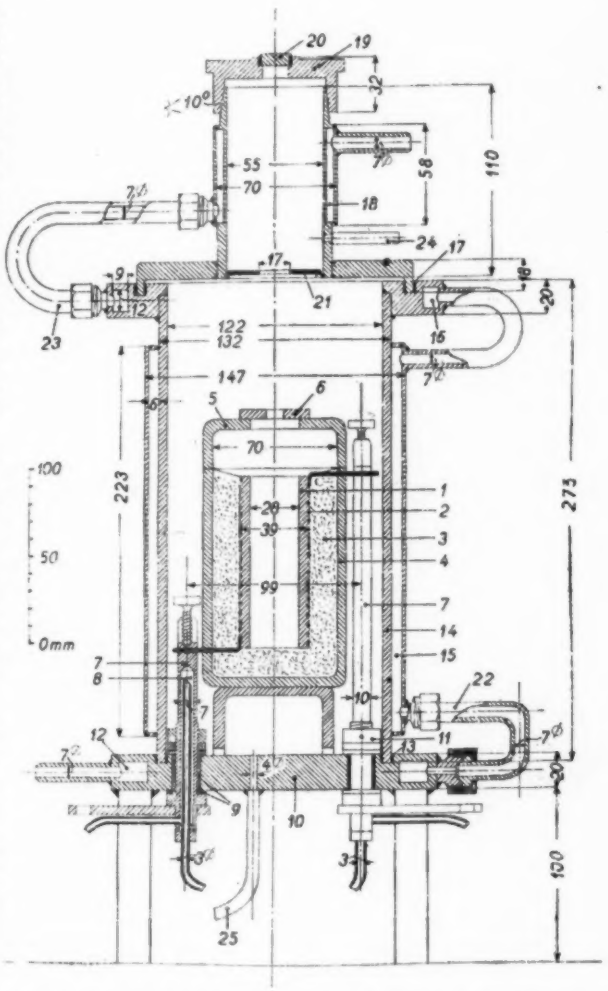

Fig. 1.—High-temperature metal resistor furnace of the core type.

* W. Kroll, presented at Electrochemical Society General Meeting, April, 1941. (Advance copy.)

molybdenum end is inserted into the molten copper and then rapidly cooled. These copper reinforced ends are then tinned and soft-soldered to water-cooled pure copper terminals.

The melting point of molybdenum[1] is 2,622 ± 10° C., that of tungsten[2] is 3,392° C. At 2,000° C. molybdenum is so soft that it is quite difficult to make it hold the shape or form fixed at lower temperatures. On the other hand, tungsten, containing a trace of oxygen, remains comparatively rigid up to 2,500° C. The vapour pressure[3] of molybdenum at 1,927° C. is $6 \cdot 07 \times 10^{-6}$ mm., as against 246×10^{-12} mm. at 1,927° C. for tungsten.[4] The evaporation of molybdenum is, therefore, appreciable at 2,000° C. and accordingly it is preferable to use tungsten at temperatures above 2,000° C., especially if contamination by molybdenum of the article being heated is to be avoided. Moist hydrogen favours the evaporation of both metals (lamp blackening phenomenon). The specific resistance[5] of molybdenum at 25° C. is $5 \cdot 78 \times 10^{-6}$ ohm/cm.^{3}, as against 59·2 at 1,927° C. The corresponding values for tungsten[6] are 5·64 and 66·25. It is evident, therefore, that between 25° and 2,000° C. the resistance increases twelvefold in the case of tungsten and tenfold in the case of molybdenum. When starting the furnace at 5 v. across the terminals when cold, we must apply about 60 v. to reach a temperature of 2,000° C. This means that a motor generator or a tap transformer with a wide regulating range has to be employed.

High-frequency furnaces provided with molybdenum or tungsten heating units are of very simple design, since no current terminals or suspension hooks are required. These units are made of 1 mm. diameter tungsten or molybdenum wire, coiled into a helix on a lathe. They are formed into "baskets" or cylinders. Similar cylinders may be made of tungsten or molybdenum powder pressed into a cylinder in a steel die and then sintered at 1,500° C. by high-frequency currents in an atmosphere of dry hydrogen or cracked ammonia. The resistors are embedded in ZrO_2 or BeO powder contained in a thin-walled alundum or alumina crucible. Furnaces of the horizontal type, embodying a series of tungsten wire cylinders of 5 mm. wall thickness embedded in ZrO_2 are very suitable for gas-sealed sintering furnaces. These furnaces operate at uniform temperature. Long bars of tungsten or molybdenum may be placed inside the cylinder on top of a thin layer of ZrO_2 to avoid short circuits.

Refractory Materials

The heat conductivity of the core is a very important factor. In the resistor furnaces described there is a temperature gradient of about 300° C. between the inside and outside wall of the refractory tube when the resistor is at 2,000° C. Therefore, if the tungsten wire is externally applied to the alumina core, the temperature of the inside wall will not be above 1,700° C. Accordingly, furnaces with inside coils are preferable. For making an inner helix, a simple procedure is as follows :—A flexible brass tube, such as a syphon tube, except that the groove is helical rather than circular, is used as pattern or mould. Moist refractory oxide powder is packed into the outside groove of the brass tube and placed into a cylindrical clay crucible. Through the bottom of the crucible is a small hole. A graphite rod placed inside the brass helix ensures a reducing atmosphere. The crucible is closed with a clay cover. The crucible is then heated to 1,500° C. in a gas furnace. The brass melts and the refractory oxide sinters and hardens, and a copper-free helical groove is formed in the refractory oxide body into which the tungsten wire or ribbon is readily fed.

One of the best refractory oxides is BeO; it is easy to mould, and requires a relatively low-firing temperature to eliminate the pores and make gas-tight tubes and other containers. Furthermore, BeO is passive towards heating units of molybdenum or tungsten. Alumina, the cheapest of the oxides, can safely be used up to 1,800° C. Silica is reduced by tungsten and molybdenum at elevated temperatures. Alundum may be successfully employed up to 1,700° C.; cores of this material are suitable for tungsten or molybdenum applied to the outside of the cores. With alundum cores, a wide range in temperature is possible.

Furnace Atmosphere

Careful consideration must be given to the furnace atmosphere. Hydrogen is by far the most suitable gas, but it is not always available in factories. On the other hand, cracked ammonia is readily prepared and safer to use than hydrogen. For making cracked ammonia, a porcelain or nichrome tube—0·5 in. diameter—may be filled with molybdenum wire scrap; connect this tube to the furnace, and while ammonia is passing through heat it to a temperature of 1,100° to 1,200° C. Most of the ammonia will be cracked and the remainder will be decomposed in the tungsten resistor furnace itself.

Vacuum furnaces are very difficult to control. With a good pump a comparatively fair vacuum can be maintained even if the furnace is not absolutely gas-tight. For ordinary metallurgical heat-treatment, a vacuum of 0·1 mm. mercury may readily be obtained with an ordinary oil pump and rubber connections. However, the preparation of gas-sensitive metals, such as titanium and zirconium, requires a vacuum below 0·001 mm. and an absolutely gas-tight furnace. Mercury diffusion pumps must then be used and all parts and connections must be metal. Furthermore, the total surface inside the furnace must be reduced to a minimum, and porous materials of construction must be avoided because they give off volumes of objectionable gases.

Proper heat insulation presents some difficulties. Metal shields made of molybdenum or tungsten sheet are of advantage. Tungsten and molybdenum wool may also be employed if care is taken to de-gas thoroughly under vacuum. The furnaces described are, in general, of the gas-seal type; some of them, however, can easily be changed over into vacuum furnaces for special high duty if the ceramic parts are replaced by refractory metal shields.

Specially Designed Furnace

One of the various types of resister furnaces developed is illustrated in Fig. 1, which shows a cross-section of a high-temperature metallic resistor furnace of the core type. The core (1) of refractory oxide may be wound on the outside or inside with molybdenum or tungsten wire or ribbon (2). The wire or ribbon is embedded in the refractory oxide, such as zirconia (3) contained in a clay crucible (4), provided with a dome (5) and a perforated cover (6). The current is introduced at (7) by means of water-cooled electrodes (8), insulated at (9) from the base-plate (10) by means of mica. The electrodes are fastened to the base-plate by means of nuts (11). Water cooling (12) protects the gasket (13). The outer furnace shell (14) is water-jacketed (15) and is provided at (16) with a cooling ring that prevents the gasket (17) from melting. The upper part of the sight tube is also water-cooled (at 18). A conically bevelled cover (19) has a quartz window (20) through which you can observe the hot zone of the furnace. A clay disc baffle (21) cuts off part of the radiation from the cover (6). The water-feed connections (22 and 23) are fastened through couplings which can be easily disconnected if necessary. Dry hydrogen enters the furnace at (24) and leaves at (25), where it burns with a small flame. All the dimensions given in the illustration are in mm.

Actual performance of this furnace is as follows :—Zirconia wire with inside helical groove; molybdenum ribbon resistor; length 1·3 metres, cross section 5 × 0·5 mm.; helix diameters 40 mm. and 54 mm., 8 turns; core height, 150 mm.; distance between two successive turns of the molybdenum helix, 18·9 mm.; maximum

1 Worthing, Phys. Rev. 2, **25**, 846 (1925).
2 Worthing, Z. Physik **22**, 9 (1924).
3 C. Zwikker, Physica **7**, 73 (1927).
4 C. Zwikker, Dissert. Amsterdam (1925).
5 Worthing, Phys. Rev. 2, **28**, 195 (1926).
6 Zwikker, C., Dissert. Amsterdam (1925); Akad. Amsterdam Versl. **34**, 469 (1925).

potential drop between two successive turns, 5 v. The energy input and corresponding temperatures of this furnace were :—

Volts.	Amperes.	Watts.	Temperature ° C.
32	78	2,496	1,520
37·5	81	3,038	1,810
41	88	3,508	1,960
44	97	4,268	2,200

The zirconia core lasts for about fifty heats at the maximum temperature of 2,200° C. when using a tungsten ribbon resistor. The zirconia core will crack at many points, due to shrinkage, but this does not interfere with its use. When molybdenum is used as resistor, molybdenum metal vapour condenses on the refractory surface and eventually this gives rise to short circuits after prolonged operation of the furnace.

Other two resistor furnaces are illustrated and described. One is a high-temperature molybdenum wire furnace, specially designed for firing large-sized silica crucibles. The heating units consist of a large number of molybdenum plus 10% tungsten alloy wire strands interwoven and reinforced with thin molybdenum strips. The furnace requires upwards of 1,500 amp. at 20 v. for a temperature of 1,800° C., but it can be operated up to 2,000° C. Another furnace carries a freely suspended tungsten wire resistor. This furnace is particularly suitable for sintering tungsten or molybdenum bars at 2,000° C. or higher.

Unsoundness in Gravity Die-Cast Silicon-Aluminium Alloy Pistons

TROUBLE experienced in the gravity die-casting of small internal combustion engine pistons in "Lo-Ex" alloy, a well-known aluminium alloy for this class of work, containing essentially 12% silicon with certain other alloying additions, led to an investigation the results of which are described by R. T. Parker.* The difficulty that had been encountered was the occurrence of unsoundness in the skirt of the piston—not at the junction of the piston wall with the runner or riser (where shrinkage might be expected), but below the gudgeon-pin bosses. The cavities were often very small and required the use of a hand lens for their detection.

The unsoundness was encountered when pistons were machined with a diamond tool under certain conditions. The disadvantage of the presence of the unsoundness lay in the danger of damaging or deranging the diamond tool, besides giving an unpleasant surface to the finished piston. A feature of the problem was that unsoundness, when it occurred, appeared to be common to the whole of the output of the foundry producing the pistons. Such an observation naturally suggests that variations in the degree of gaseous contamination might be at the root of the problem, but since it was known that attention to this aspect had not resulted in complete solution of the problem, work was undertaken to investigate several other factors, particularly gas contamination, the temperature of the die assembly in which the pistons were cast, and machining technique.

The effect of atmospheric conditions was investigated, daily readings of wet- and dry-bulb thermometers being taken over a period, but the correlation of these conditions with the percentage of scrap pistons was found to be difficult, since there are many other factors which obscure the results. To establish the relationship quite definitely, the unpractical procedure of casting pistons without any attempt to improve the return of good pistons would be most effective. As it is, there is a natural reaction to do everything possible when the percentage of the scrap rises, so that an increase in humidity under such conditions may be accompanied by a slight rise and then a rapid fall in the percentage of the pistons scrapped.

An examination of pistons, after diamond machining by independent operators, showed that small cavities may be disclosed or concealed according to the technique adopted, and in subsequent work it was necessary to keep a close watch upon the standard of machining used in examining test pistons. In certain cases pistons which were superficially sound—that is, had passed the machining test—were found to be unsound about the inner surface of the skirt. It was considered that this might be due to differences in the temperatures of the die and core, and the effect of known variations in such temperatures was investigated. As the work proceeded, it became evident that the gas content of the metal was also playing a part in determining the mode of occurrence of unsoundness, and the work was extended to compare the results of using metal low and high gas content under known temperature conditions in the die-assembly.

Two experiments, in which pistons were cast from metal having a high or low gas content into a die-assembly fitted with thermocouples, demonstrated clearly the effects of variation in the gas content of the metal and temperature of the die-assembly. Of micrographic and X-ray methods of examination, the latter proved far more useful in assessing the soundness of the pistons. A well-marked relationship between soundness and die-assembly temperature was observed, the hotter assembly giving the better results. With metal of high or low gas content, pistons of reasonable soundness were obtained at higher assembly temperatures ; but at lower assembly temperatures the metal of low gas content gave pistons of inferior quality containing localised unsoundness. Pistons from metal of high gas content contained unsoundness of a finer and more general type, owing to the dispersive effect of the gas present.

As a result of the work described, the explanation of the type of unsoundness encountered is thought to be gas contamination to a variable degree. This must be due to fluctuations in the usual sources of gas contamination, such as changes in atmospheric conditions and in melting practice. The effect of variation in gas content has been to alter very markedly the form of the gas-shrinkage unsoundness, which is always present to some degree. When the gas content is low, the unsoundness may be easily recognised as being, to a large extent, due to shrinkage, and furthermore such coarse unsoundness tends to be more or less central and less likely to be disclosed by superficial machining.

When the gas content was higher, a general type of unsoundness was found, and this persisted although the temperature of the die-assembly was raised appreciably. Increasing the die-assembly temperature with low-gas metal resulted in a rapid diminution of what could be identified as shrinkage. It is thought, therefore, that although the unsoundness at any time is probably due to both gas and shrinkage operating together, yet gas is the more important factor, being responsible for the appearance of unsoundness on the surface of the machined pistons.

* *Journal of the Inst. of Metals.* Part 3, **67**, pp. 101-114.

New molybdenum and tungsten works, claimed to be the largest in Europe, recently commenced operations in Kabardino-Balkaria, in the heart of the Caucasian mountains. Prospecting for ores in this area began in 1934, and at the altitude of 9,850 ft. large deposits of molybdenum and tungsten were discovered, also gold, tin, antimony, arsenic, copper and lead. Many difficulties have been overcome, but the whole plant is fully mechanised and modern methods of extraction are in operation.

Atmospheric Exposure Tests on Copper-Bearing and other Irons and Steels in the United States

THE results of atmospheric exposure tests of 12 different irons and steels for a period of five years at three locations in the United States of America are reported by Ewart S. Taylerson,* as a result of a suggestion made by Dr. U. R. Evans to compare corrosion rates of steels in the United States with those obtained at the various exposure stations of the Corrosion Committee of the Iron and Steel Institute. The specimens tested include three steels, containing 0·03%, 0·1% and 0·5% of copper, corresponding to the steels X, Y and Z, tested by the Corrosion Committee and referred to in its first report. The remaining specimens tested comprise six steels ranging in copper content from very low to 0·5%, a copper-bearing wrought iron, and two low-alloy steels. The last nine materials were of American origin and were selected to illustrate the large difference in corrosion rate that can be obtained owing to variation in analysis. The analysis of the materials are given in the following table:

Material.	C. %	Mn. %	P. %	S. %	Si. %	Cu. %	Ni. %	Cr. %
Committee's steel X * (0·03% Cu)	0·18	0·61	0·041	0·043	0·008	0·03	0·05	0·04
Committee's steel Y * (0·26% Cu)	0·19	0·60	0·040	0·043	0·009	0·26	0·05	0·05
Committee's steel Z * (0·54% Cu)	0·20	0·62	0·038	0·043	0·010	0·54	0·05	0·05
Committee's pollution specimens (ingot iron)	0·02	0·05	0·013	0·044	0·008	0·07	0·05	0·001
Experimental heat, low Mn and Cu	0·015	0·02	0·004	0·038	0·004	0·02	0·006	0·003
Experimental heat, medium Mn, low Cu.	0·040	0·24	0·062	0·032	0·008	0·01	0·002	0·009
Open-hearth iron, very low Cu	0·018	0·025	0·005	0·019	0·002	0·08	0·002	0·01
Steel S (0·05% Cu)	0·040	0·49	0·074	0·042	0·003	0·05	0·006	0·09
Wrought iron (0·29% Cu)	0·018	0·095	0·096	0·028	0·14	0·29	—	0·006
Steel K (0·27% Cu)	0·026	0·47	0·066	0·045	0·003	0·27	0·03	0·03
Bessemer steel (0·5% Cu)	0·10	0·40	0·107	0·057	0·007	0·52	0·002	0·02
3·5% Ni steel	0·043	0·46	0·014	0·027	0·004	0·06	3·52	0·16
Cr-Si-Cu steel	0·11	0·62	0·012	0·006	1·25	1·03	0·07	3·88

* *See* First Report of the Corrosion Committee, *Iron and Steel Institute*, 1931, *Special Report No.* 1, pp. 97, 98. The original 15 × 10 × ⅛-in. specimens used for rolling the sheets were: X110813, X110814, X110910, X110911; F111413, F111414, F111510, F111511; Z112013, Z112,014, Z112,110, Z112,111.

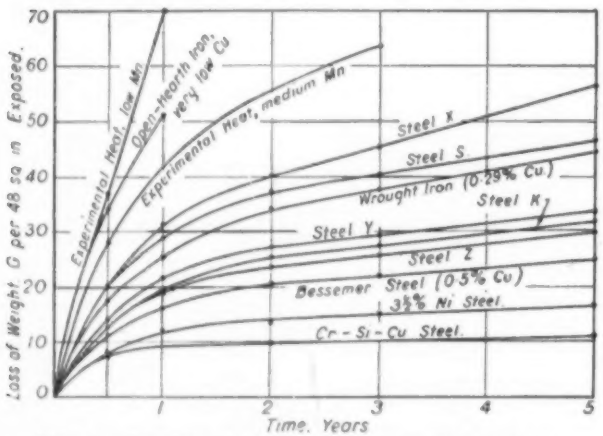

Fig. 1.—Results of atmospheric corrosion tests at Kearny, New Jersey (industrial marine atmosphere).

The locations of the exposure tests included an industrial district on marine marshes, an inland industrial district and a rural district, at Kearny, New Jersey; Vandergrift, Pennsylvania; and South Bend, Pennsylvania, respectively. The results of the tests, shown in Figs. 1, 2, and 3, indicate that marine industrial atmosphere at Kearney, where the specimens remained comparatively clean, was considerably more corrosive than at Vandergrift, where the specimens were subjected to deposits of soot and cinders. This increased corrosion rate may have been due to the high humidity and the contaminated marine marsh atmosphere. The corrosion rates at South Bend, Pennsylvania in the rural atmosphere are very much lower, as shown in Fig. 3, and it was necessary to plot the results of several steels in a single band to avoid confusion.

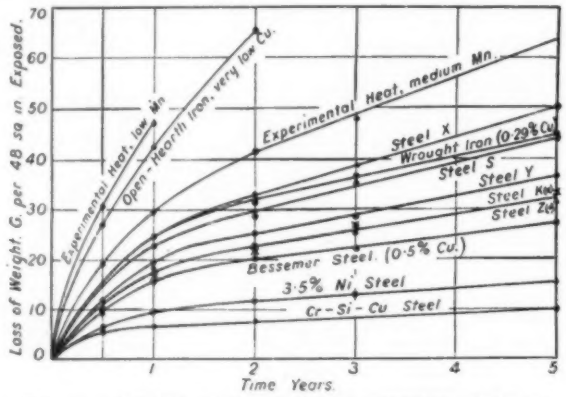

Fig. 2.—Results of atmospheric corrosion tests at Vandergrift, Pa. (industrial atmosphere).

It is interesting to note that at these locations the effect of the addition of copper in the case of the Committee's steels was much more pronounced than that shown in the results published by the Committee for other locations It is believed that this difference may be due to the specific nature of these industrial atmospheres, which seem to have a pronounced tendency to form harder and more adherent scales on the high-copper steels. The differences noted are considerably less under rural conditions.

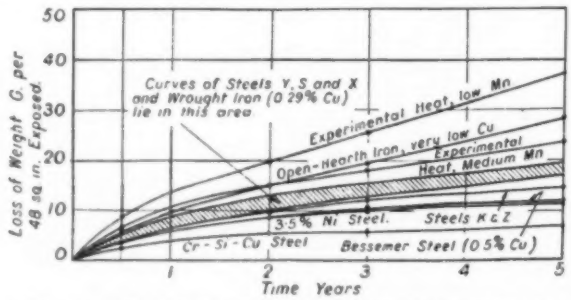
Loss of Weight G per 48 sq in Exposed.
Time Years
Curves of Steels Y, S and X and Wrought Iron (0·29% Cu) lie in this area
Experimental Heat, low Mn
Open-Hearth Iron, very low Cu
Experimental Heat, Medium Mn
3·5% Ni Steel.
Steels K & Z
Cr-Si-Cu Steel
Bessemer Steel (0·5% Cu)

Fig. 3.—Results of atmospheric corrosion tests at South Bend, Pa. (rural atmosphere).

The results of the whole test confirm those of other investigators, in that very pure materials low in copper have high corrosion rates, which, however, are decreased by the slight additions of manganese and phosphorus. Among the commercial steels it is apparent that the effect of phosphorus is beneficial when combined with copper. The two higher-alloy steels show a significant increase in corrosion resistance.

* Iron and Steel Institute, Annual Meeting, 1941. Paper No. 4/1940 of the Corrosion Committee (communicated by Dr. W. H. Hatfield, F.R.S.). (Advance copy.)

The Practice of Marketing of Aluminium—Part III.

By Robert J. Anderson, D.Sc.

The practice of marketing aluminium, more especially in respect of its technical and commercial details, has been dealt with rather scantily in the literature, and the purpose of this article is to give a broad view of the practice. Applications will also be considered briefly in order to show the range of the market. The marketing of aluminium and its manufactures is necessarily conditioned by the kind of products and their field of use, and future developments will increase the range.

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Hardeners

INTERMEDIATE aluminium alloys constitute another class of raw products marketed in the aluminium trade. These alloys are usually called hardeners or rich alloys. They are employed for making fixed additions of metals to aluminium in the preparation of light alloys. The industrial hardeners are alloys of aluminium with one or more metals of relatively high melting points. Binary intermediate alloys may contain about 5 to 50% of the alloying metal and remainder aluminium. Complex hardeners contain aluminium and two or more other metals in suitable proportions for making light alloys of required composition.

In general, the use of intermediate alloys facilitates procedure in preparing light alloys of aluminium with metals which melt at high temperatures. The melting point of 99+% aluminium is about 657° C., and the melting points of some alloying metals range from 1,083° C. for copper to 1,800° C. for titanium. Most metals which melt at high temperature dissolve slowly in liquid aluminium, tend to segregate, or are not readily procurable in suitable form for making direct fixed additions. Suitable intermediate alloys melt at relatively low temperatures and dissolve rapidly in aluminium. Most of these alloys can be easily broken to yield small pieces for accurate weighing.

A series of standard intermediate alloys has been developed to provide for the general needs of practice. These include compositions which contain more or less aluminium and one or more other metals—for example, copper, iron, manganese, nickel and silicon. The hardener usually employed for adding copper contains 50% copper and 50% aluminium, but the 33% copper alloy is also used. Iron may be added as a composition of 5 or 10% iron and remainder aluminium. An alloy containing about 10% manganese and 90% aluminium is suitable for introducing manganese. Hardeners composed of 10 to 25% nickel and remainder aluminium are employed for adding nickel. Several compositions containing from 20 to 50% silicon and remainder aluminium are used for introducing silicon; the lower content is preferred for making light alloys lean in silicon. Among complex hardeners may be mentioned compositions which contain aluminium, copper, and iron; aluminium, copper, and manganese; aluminium, copper, and nickel; and aluminium, copper, and silicon. Intermediate alloys are not necessary for making fixed additions of metals which melt at relatively low temperatures. Magnesium and zinc, for example, are added directly to aluminium in preparing light alloys.

Intermediate alloys are made by several processes, but most of the output is produced by the direct alloying of aluminium with the required metals in a melting operation. The general method is to melt aluminium and add small pieces of the metal to be alloyed. Intermediate compositions with copper, iron or nickel are usually prepared in this way. Other processes include the following:—(1) Electrolytic reduction of metal oxides or salts with alumina in the Hall-Héroult cell; (2) thermit (aluminium) reduction of metal oxides; (3) aluminium reduction of metal salts; and (4) carbon smelting. Considerable quantities of intermediate aluminium alloys have been produced by the second method, particularly manganese-bearing compositions. Some aluminium-silicon alloys are made by the last method.

Intermediate alloys are marketed by primary and secondary aluminium companies, special alloy makers, and producers of thermit metals. The basis of grading is chemical composition. These alloys may be supplied in the form of notched or plain ingots and waffle plates. Crushed material is also furnished in the case of some compositions. This may be sized by screening. Pea and nut are the usual sizes. Intermediate alloys are used in foundries, die-casting plants, rolling mills, and other shops where light alloys are produced. Many consumers make their own supplies.

Semi-Finished Manufactures

The term semi-manufacture is usually employed to denote products which are to be worked further in making finished goods, but it may also be applied to include parts for assembly in structures or material for use in a wide variety of processing operations. Sundry products may be classed as semi-finished or finished depending upon the application. And, in some cases, the demarcation may be a matter of definition.

Fig. 1 is an outline diagram which indicates the principal kinds of products made from aluminium and its alloys.

Among the various kinds of semi-finished aluminium manufactures the following are the principal forms: Castings, sheet and sheet products (including coil, flattened coil, strips, circles, etc.), plate, foil, bars, rods, wire, shapes and sections, tubing, moulding, and powder. All these manufactures are supplied by the large primary aluminium producers. Numerous non-integrated companies make a few kinds of semi-finished material or only one product as a speciality. Sheet and related manufactures, structural shapes, bars, and rods are rolled from ingots. Foil is produced by the further rolling of coiled sheet. Tubing, moulding, bars, rods, and many sections are made by the extrusion of ingots. Forgings may be worked from ingots, rolled slabs, or other semi-processed material. Wire is drawn from rods. Powder is made by comminuting small pieces of light sheet or foil scrap. Apart from foil and powder, semi-manufactures in general are made of both 99+% aluminium and alloys. Two main classes of alloys are employed, namely, compositions for casting and compositions for working. Each class comprises alloys to be heat-treated and to be used without heat-treatment. Substantially pure aluminium is, of course, a lean unintended alloy.

The so-called aluminium castings of industry are nearly always made of alloys, but some products are cast in the substantially pure metal. Cast parts are produced by five essentially different processes. These are: Sand, die, permanent mould, centrifugal, and slush casting. The latter two are relatively unimportant, but are employed

in some shops for special parts. In general, the method of manufacture is determined by the design of casting, properties required, weight and size, number of pieces, tolerances allowed, and cost. Sand casting is the method indicated for making a small number of pieces, large castings, and parts which require intricate coring. When applicable, the die-casting or permanent-mould method is indicated for producing large numbers of castings. Machining is rendered unnecessary or minimised by die-casting. Maximum mechanical properties and soundness of as-cast parts are obtained by permanent-mould casting. Most aluminium-alloy pistons are made by this process. In respect of dimensional limits the order of accuracy is: Most precise die-castings; next, permanent mould castings; and last, sand castings. It is to be understood, of course, that the tolerances set in practice are conditioned not only by the method of manufacture, but also by the particular casting.

Fig 1.—Principal kinds of aluminium products; raw, semi-finished, and finished.

Aluminium-alloy castings are employed mostly as parts of equipment and structures. The largest market for these products is the automobile industry. They are used for engine, chassis, and body construction in all types of motor-vehicles. Cast products are also employed in the manufacture of aircraft, washing machines, vacuum cleaners, Diesel engines, outboard motors, electrical equipment, portable tools, various kinds of machinery, railroad and street railway cars, chemical apparatus, and cooking utensils. Numerous other uses might be mentioned, but this short list indicates that the market is extensive. Cast parts are produced by many companies, and the principal independent interests which supply the market are jobbing foundries and manufacturers of die-castings. A large number of companies make castings solely for their own use.

Aluminium and various alloys are rolled for the production of flat sheet and coil. Several forms of material are made from these products including strips, bands, flattened coil, circles, squares, etc. Sheet material is supplied in a wide range of gauges and sizes. In American practice sheet is usually rolled to thicknesses in conformity with the Brown and Sharpe gauge, from about No. 10 to No. 36, corresponding to 0·1018 and 0·005 in., respectively. The Birmingham sheet and Standard wire-gauge systems have been employed in England, and the practice in Continental Europe is to roll to standard thicknesses measured in millimetres. Flat rolled sheet thicker than about $\frac{1}{16}$ in. is called plate. The term foil is generally applied to sheet material thinner than about 0·005 in. Sheet is usually made with a highly-polished surface finish. Aluminium and some alloy sheet heavier than about No. 18 gauge is also produced with a dull surface finish. This material is called grey plate. Aluminium and unheat-treated alloy sheet products are supplied in several tempers from soft to hard. The common intermediate tempers are one-quarter, half, and three-quarters hard. Temper other than soft is controlled by regulating the amount of cold work on annealed material It is a measure of the mechanical properties, and hence of the cold formability. The properties of duralumin and other strong alloys are controlled by suitable heat-treatment.

Coiled sheet is employed mostly in high-speed press work for the manufacture of small stamped or drawn wares, especially cooking utensils and other light hollow goods. Flat sheet is used where material of large size, close tolerances, bright surface, or exact flatness is required. A few applications are for panels, building, transportation equipment, chemical apparatus, the fabrication of certain radio parts, and lithographic plates. Flattened coil costs less than flat sheet, and may be used to advantage if an especially bright surface or precise flatness is not required. Bottle seals, jar caps, and other closures are made of light gauge sheet. Unheat-treated alloy sheet is employed where greater rigidity is needed than can be obtained with substantially pure aluminium, particularly in the hard temper, for some simple forming operations, and as corrosion-resistant material. Heat-treated alloy sheet is used in the construction of aircraft and other transport equipment as well as generally where the main requirement is high tensile strength. Clad sheet, so called, consists usually of a heat-treatable alloy core coated with a coherent layer of high-purity aluminium. It fulfills requirements for sheet which is both strong and exceptionally resistant to corrosion. Broadly, the market for aluminium and alloy-sheet manufactures is the general metal-fabricating industry.

Aluminium foil may be rolled in practice to about 0·0002 in. thick, but material from about 0·0003 in. to 0·0006 in. is suitable for most demands. A special grade of metal low in impurities is used for foil. The regular market-forms are coils and cut rectangles. Foil may be plain, printed, lacquered, embossed, or coloured, and interleaved with paper or paper-mounted. Large quantities are used for wrapping food products, tobacco, and numerous articles which must be protected against the effects of handling, light, and the air. Foil has also been employed extensively in condensers for radio and other equipment and for electrical contacts. A recently-developed application is as a thermal insulator, either as flat foil attached to a surface or as crumpled filler in an air-space. Other uses are for bottle caps and liners, reflectors, and in printing. The uses of aluminium foil indicate its wide market. It is sold direct by the producers and also by jobbers.

Among other wrought semi-manufactures of aluminium and its alloys are included bar, rod, and wire. These forms are either rolled to size or rolled and then drawn. Long and solid pieces of simple contour, other than round, are termed bars if the greatest dimension of the transverse section is about $\frac{3}{8}$ in. or more. Round bars are called rods. Wire is the term applied to rod- or bar-shaped material which measures less than about $\frac{3}{8}$ in. on the greatest cross-sectional dimension. These products are made in a considerable range of standard sizes—bars up to about 6 in. wide, rods up to about $4\frac{1}{2}$ in. in diameter, and wire as small as 0·00025 in. in diameter (No. 42 Brown and Sharpe gauge). Bar stock is employed mostly for machining and forging. Aluminium busbars are used considerably for

the transmission of electric current. In general, rods are applied for the same purposes as bars. Free cutting machining rods of special compositions has been recently developed. Reference has previously been made to metallurgical rod used for deoxidising steel. Structural shapes constitute another class of rolled products. These are made of heat-treatable alloys and in the form of I-beams, channels, angles, and other sections. Such shapes are adapted for motor-vehicle, railroad-car and bridge construction.

The most important use of aluminium wire is as cable for the transmission of electricity. There are three principal kinds of cable, namely, stranded aluminium with a steel core (so-called aluminium cable, steel reinforced), all-aluminium, and alloy. The preferred compositions for alloy cables are made by adding small controlled amounts of magnesium and silicon to aluminium low in impurities. Aluminium-alloy cable of this type is heat-treated. Aldrey and Almelec are two trade alloys used for cables. Drying racks, screens, and dipping baskets are woven of aluminium wire, and flexible conduit or tubing is made of flattened wire. Other uses of aluminium wire are for welding rod, fuses and field coils.

Thousands of different shapes are made by extruding aluminium alloys. The extrusion method is especially applicable for the manufacture of stock with intricate contours which cannot be produced cheaply by any other process. In the case of heavy sections the maximum dimension of extruded stock may be up to 5 in. on the cross-section, and for light sections it may be up to 6 in. The thickness is usually more than $\frac{1}{8}$ in. Extruded material includes moulding, angles, channels, beams, tees, special sections for building and aircraft construction, strips for stair treads, and various kinds of trim. The uses of extruded products are very numerous.

Aluminium and alloy round tubing is produced in various sizes from about $\frac{1}{2}$ in. to 10 in. in diameter. Both standard tube and heavy iron-pipe wall thicknesses are made. The usual forms of pipe fittings required for the many kinds of piping connections and arrangements are also manufactured. Streamline tubing for aircraft construction is produced in numerous shapes and sizes. And a considerable variety of special tube shapes for architectural work has been developed in recent years. Some uses of round tubing include the following: For wiring conduit, water piping in textile and paper mills, construction of chemical apparatus (for example, heating and cooling coils), pneumatic conveyers, and feed-lines for lubricants and gasoline. An important application is as mandrels in the manufacture of rubber tyres, tubes and hose.

Aluminium-alloy forgings are generally made of heat-treatable compositions and are employed mainly for highly-stressed parts in place of castings. In respect of mechanical properties heat-treated forgings are considerably better than heat-treated castings. Also, forgings may be used for shaping parts which cannot be fabricated cheaply enough by some other process. Following are some applications of forgings: Aircraft propellers, various parts of aviation engines (crankcases, cylinder heads, and pistons), connecting rods for automobile engines, hardware, fixtures, horse shoes, structural members of trucks for street railway cars, and locomotive side-rods.

Aluminium powder is made by a stamping operation in which small pieces of light sheet or other suitable material are hammered by mechanical stamps or else comminuted in a ball mill. The finished product is graded by sifting or by air separation. It is in the form of minute flakes. Most kinds of powder are polished. During the polishing process the flakes become coated with an exceedingly thin film of lubricant which imparts the power of leafing. Powders are graded and classified differently by the various makers, but the basis is screen size. Standard varnish powder of the Aluminium Company of America passes 140-mesh and about 50% of the material may pass 325 mesh. The appearance of aluminium powder is affected markedly by the relative proportions of small and large flakes and by the size of the largest flakes. A new form of aluminium powder has been marketed within recent years. This is aluminium paste. It contains 65% powder, the remainder being mineral spirits.

Aluminium powder is employed extensively as a paint pigment, and most of the output is consumed for this purpose. Aluminium paint is suitable for both indoor and outdoor applications. It is valued for its high reflectivity, low emissivity, and opacity, as well as for good resistance to corrosion and penetration by moisture. Aluminium paint is used for factory interiors, bridges, oil tanks, furnaces, refrigerator cars, and outdoor ironwork in general. It is also applied as a primer for wood. Other uses of aluminium powder are in printing, coating balloon fabrics and paper, the manufacture of solid rubber truck tyres, fireworks, ordnance (flares and star shells), the cyanide process for gold and silver ores, for making aerated concrete, and as a constituent of drainpipe cleaner. A number of small companies produce aluminium powder exclusively.

Grained aluminium is used mostly in the thermit process for welding and reduction. This material is made by stirring aluminium slowly while it is freezing. The metal breaks up into small irregular grains which are about $\frac{1}{64}$ in. thick and up to about $\frac{1}{4}$ in. wide or long.

(To be continued.)

Naturally Alloyed Vanadium Pig-Iron

As a result of some experimental research carried out at the Teplogorsky Metallurgical Works, naturally alloyed vanadium pig-iron has been produced, in a charcoal furnace, from Kusinsk titano-magnetites. This vanadium pig-iron, which is free from sulphur and phosphorus, is claimed to be the first to be produced. In manufacturing high-quality vanadium steels in open-hearth furnaces, charcoal iron is generally used and ferro-vanadium, produced in the electric furnace, is added. It is claimed that the use of naturally-alloyed vanadium simplifies and cheapens manufacture and tends to improve the quality of the vanadium steel produced.

Soviet Mineral Resources

THE increasing need for minerals has caused continual search to discover the world's resources. Several countries have concentrated on the exploration of territory for this purpose, notably the United States, Canada, and the Soviet Union. Seven expeditions are being sent out by the latter country this year. Three of these expeditions will continue work began a few years ago in the Urals, the Caucasus and the European plain. The other four will explore district in Eastern Siberia, the Altais, the Carpathians and the Kola peninsula.

The Carpathian expedition is to make a comprehensive study of the stratigraphy, tectonics and petroliferousness of the chalk deposits of the territory between the towns of Drogobycz and Nadvorny, and will also explore the Central Carpathian zone for oil. New deposits of tin, manganese, poly-metallic ores and gold have been discovered in the Altais in recent years, and the expedition is to prospect for new ores in this area. The East Siberian expedition has planned to explore the entire south-eastern section of the Siberian plain and the more important oil districts.

Herbert Jackson Prize

The London Midland and Scottish Railway announce that the Herbert Jackson Prize for 1940 has been awarded to Mr. S. C. Britton, of the Metallurgical Department (Engineering Section), Derby, for his paper entitled "The Corrosion of Copper and Some Copper Alloys in Atmospheres Highly Polluted with Coal Smoke."

Organic Finishes on Zinc-Base Die-Castings

By E. E. Halls

Two main types of chemical pre-treatment processes to render the surfaces of zinc die castings inert are discussed, and results are given of tests carried out to determine the relative merits of each process. Stoving synthetic enamels are stated to be best for zinc die castings, being uniform in quality, easy to apply, rapid baking, and of excellent durability.

THE securing of adherent lacquer or enamel coatings on zinc is not a simple matter and it involves some pre-treatment process to render the zinc surface inert, as well as the choice of reasonably good-quality lacquers or enamels having in themselves a naturally good quality of adhesion and flexibility. If even the best-quality materials are applied direct to zinc, and even if initially quite good adhesion is secured, this rapidly reduces, and after a few weeks either the enamel is embrittled and flakes away or it becomes softened and can easily be pulled off with the thumb nail. This trouble is probably associated with reaction between zinc and acidic constituents in the coating in the presence of moisture. The moisture which normally penetrates by diffusion through the film is sufficient to promote the deterioration. By ensuring a more intimate contact between the coating and the base metal by roughening the latter with sand or shot blasting, the rate of deterioration is appreciably decreased. It is likewise lessened by choice of some of the more impermeable film-forming materials such as the cellulose-glyptal-resin combination lacquers and the ready mixed aluminium paints and enamels. Even in such cases, however, performance is not good, or where it is reasonably good the product only has a limited application.

To overcome the difficulty two main types of chemical pre-treatment processes by immersion have been developed, one based upon a phosphate and one upon a chromate type of solution. These treatments convert the surface of the zinc into relatively inert compounds which, under normal conditions, are virtually unaffected by moisture beneath the enamel film, or fail to react with the acidic resins or fats in the enamel coatings. Many forms of these treatments are in operation successfully, and, in general, they can be stated to overcome entirely the difficulties encountered. The phosphate treatments are illustrated by the Parkerising PZ method, in which the clean work is immersed for 10 to 15 mins. in a solution of proprietary chemicals, short of boiling at about 210° F. The solution is easily maintained by chemical analysis and daily additions. The work surface is converted into a dark greyish coloured film which is quite absorbent, and which, apart from providing the inert film, gives an additional chemical key to the paint or enamel. The modern phosphate processes for steel have also been rendered suitable for the same purpose, and thus the bonderite D solution is suitable with immersion times of 3 to 5 mins. at 175° to 185° F. This type of solution gives visually an almost imperceptible coating—usually a slight dulling or greyness of the surface. With some castings, for reasons of surface, it does not take unless the skin of the casting be first broken by sand or shot blasting. The coating given by this type of solution is not quite so efficient as that given by the first-mentioned one, although for most practical purposes it is adequate. The long immersion method in the special solution seems to ensure that the enamel coating, whether cellulose or synthetic, retains its original characteristics better and tenaciously adheres even under very rough usage.

Two other similar processes are the granodising methods, in which the special solution for zinc employs 10 to 15 mins. immersion at about 175° C., and the solution, which is suitable for both steel and zinc, uses the short period immersion. Similar comments apply.

The chromate processes are also proprietary or patented, and generally are a little more fastidious in carrying out than the phosphate methods. On the other hand, they give rather better performance, and they in themselves provide a protective coating for the zinc, which the phosphate processes do not, as well as causing the organic coatings to retain their characteristics and adhesion over long periods, even at sharp edges and prominences.

Typical average durability test results to represent numerous exposure tests that have been made from time to time are summarised in the attached tables, Nos. I to IV. The castings employed for the purposes of these tests included both the straight aluminium alloy, such as Mazak 3, and the copper containing alloys such as Mazak 2 or Mazak 5. The tests included enamel finishes direct upon the plain castings, and upon castings after chemical pre-treatment by one of the phosphate processes or by a chromate method.

In the tables the phosphate processes A, B, C and D refer to the long immersions (A and C) and to the short immersion processes (B and D), respectively. The work for the specimens without chemical pre-treatments was thoroughly cleaned free from oil, grease and swarfe in a liquor-vapour trichlorethylene degreaser. That for the phosphate processes, and where any pre-treatment was given, was given a preliminary clean either in trichlorethylene or in a hot aqueous solution of 4 oz. of sodium metasilicate per gallon. For the phosphate treatments the parts were wired and immersed, and after treatment were thoroughly water washed and dried. The B and D treatments included, after the water rinse, an immersion for 30 secs. in 0·05% chromic-acid solution at 175° F. and then immediately drying off. With the chromate processes, work was cleaned in a mixture of 8 oz. of caustic soda and 8 oz. of sodium fluoride per gallon, operated at 170° C. and followed by water rinsing. It was treated in the chromate solution by immersion for 10 secs. at ordinary temperatures and then rinsed in water and dried off. The chromate solution consisted of 2 lb. of sodium bichromate and $2\frac{3}{4}$ oz. of sulphuric acid per gallon. It is pointed out that with this process drying has to be achieved without heating, but either by a current of air or by centrifuge. Further, the chromated parts are allowed several hours in which to age before enamelling.

The fastidious points about the chromate treatment are : (*a*) ensuring that parts do not dry off between operations, (*b*) to keep it maintained in balance, this having to be done by trial, (*c*) avoidance of over-washing of the parts treated, and (*d*) avoidance of heating them to dry them. If given proper attention these features should cause no trouble.

The tabulated test results are self-explanatory and establish beyond any doubt that some method of pre-treatment is essential and that any of the methods mentioned are satisfactory.

Table I covers the results of standard salt spray tests. The test conditions comprised exposure of the specimens to the atmosphere produced by atomising 20% salt solution with compressed air. This spray was produced

TABLE I.—DURABILITY TEST RESULTS—"FINISHED" ZINC BASE DIE CASTINGS EXPOSED TO SALT SPRAY.

Sample No.	Organic Finish.	No Chemical Pre-treatment.	Phosphate Immersion Treatment.				Chromate Immersion Treatment.
			A.	B.	C.	D.	
1	Zinc chromate primer, stoved glossy brown finishing enamel, stoved.	Adhesion poor in one week, blistering and easily peeled in three weeks.	Corrosion from edges, corners and holes in three weeks, otherwise still good in four weeks.	Slight corrosion at edges and very slight embrittlement of finish in four weeks. Condition still good.	Some corrosion from sharp corners and edges in three weeks, otherwise sound in three weeks.	Slight white corrosion at corners and holes, slight embrittlement of finish in four weeks. Condition good.	Entirely unaffected in four weeks.
2	Red oxide primer, stoved glossy brown finishing enamel, stoved.	ditto	ditto	ditto	ditto	ditto	ditto
3	Two coats glossy brown finishing enamel, stoved.	ditto	ditto	ditto	ditto	ditto	ditto
4	Two coats glossy brown cellulose enamel.	ditto	ditto	Cellulose embrittled and adhesion fair in four weeks.	ditto	Cellulose rather brittle and tending to detach in four weeks.	Slight embrittlement of cellulose, but adhesion still good, no corrosion, in four weeks.
5	One coat aluminium cellulose enamel.	Adhesion very poor in four weeks.	ditto	Slight corrosion of edges, slight softening of finish, and a little loss of adhesion in four weeks.	ditto	Slight corrosion and loss of adhesion near edges in four weeks.	Entirely unaffected in four weeks.
6	One coat aluminium stoving enamel.	Finish tended to soften and adhesion become very poor in four weeks.	Corrosion from edges, corners and holes in three weeks, otherwise adhesion still good in four weeks.	Slight corrosion of edges, slight softening of finish and a little loss of adhesion in four weeks.	ditto	Slight corrosion and slight softening of enamel in four weeks.	Entirely unaffected in four weeks.
7	One coat aluminium stoving enamel, one cost stoving varnish	ditto	ditto	ditto	ditto	ditto	ditto
8	One coat special clear cellulose lacquer.	Little apparent affect in four weeks.	Fairly general corrosion in four weeks.	Tendency to very slight general corrosion in four weeks.	Fairly general corrosion in four weeks.	Tendency to very slight general corrosion in four weeks.	ditto

in a closed cabinet and passed up through glass baffle plates to remove the heavier drops. The specimens were freely suspended. One day's test comprised an 8-hour working day with the spray operating, and the remainder of the day with the samples in the cabinet and the spray off. Specimens were washed in water and dried with a soft cloth for examination daily.

It will be seen that the behaviour of the specimens with the various types of finishes is clearly defined according to the pre-treatment given to the specimens. All those with no chemical pre-treatment are poor, with the enamel coatings rapidly losing adhesion. The various types of inhibitive primers (zinc chromate and red-oxide pigments), as is seen by samples Nos. 1 and 2, have no additional benefit, and exhibit none of the special merits that they do on magnesium alloys or on iron and steel. The ready mixed aluminium media generally are slightly superior, and the sprayed thin, clear cellulose lacquer, which in effect is a combination lacquer of nitro cellulose and glyptal resin, gives quite good performance, although obviously it has limited application.

Of the phosphate-treated samples, the processes A and

TABLE II.—DURABILITY TEST RESULTS—"FINISHED" ZINC BASE DIE CASTINGS EXPOSED TO HUMID ATMOSPHERE.

Sample No.	Organic Finish.	No Chemical Pre-treatment.	Phosphate Immersion Treatment.				Chromate Immersion Treatment.
			A.	B.	C.	D.	
1	Zinc chromate primer, stoved glossy brown finishing enamel, stoved.	Adhesion poor, enamel "soft" and easily peeled off in four weeks.	Entirely unaffected in two years.	Slight embrittlement and loss of adhesion perceptible in six months. Little further change in one year.	Entirely unaffected after two years.	Slight embrittlement and loss of adhesion perceptible in six months. Little further deterioration in one year.	Entirely unaffected after two years.
2	Red oxide primer, stoved glossy brown finishing enamel, stoved.	ditto	ditto	ditto	ditto	ditto	ditto
3	Two coats glossy brown finishing enamel, stoved.	ditto	ditto	ditto	ditto	ditto	ditto
4	Two coats glossy brown cellulose enamel.	Enamel very brittle and easily flaked off in three weeks.	Slight embrittlement of cellulose enamel, otherwise unaffected in two years.	Embrittlement of cellulose and appreciable loss of adhesion in three months.	Slight embrittlement of cellulose enamel, otherwise unaffected in two years.	Embrittlement and some loss of adhesion in three months	Slight embrittlement of cellulose enamel, otherwise unaffected in two years.
5	One coat aluminium cellulose enamel.	Adhesion poor in seven weeks.	Entirely unaffected in two years.	Virtually unaffected in one year.	Entirely unaffected in two years.	Virtually unaffected in one year.	Unaffected in two years.
6	One coat aluminium stoving enamel.	Adhesion poor, enamel "soft" and blistering, and could be peeled off in three weeks, very easily in eight weeks.	Entirely unaffected in two years.	Virtually unaffected in one year.	Entirely unaffected in two years.	Virtually unaffected in one year.	Unaffected in two years.
7	One coat aluminium stoving enamel, one coat stoving varnish.	ditto	ditto	ditto	ditto	ditto	ditto
8	One coat special clear cellulose lacquer.	Adhesion unimpaired in twelve weeks, reasonably good in one year, otherwise unimpaired.	Lacquer too thin to give reasonable finish, becoming whitish in six months.	ditto	Lacquer too thin to give reasonable finish, becoming whitish in six months.	ditto	ditto

C, which in effect give a much thicker phosphate coating, are appreciably superior to B and D, although the last two give exceedingly good performance in comparison with the untreated specimens. The chromate-treated samples showed up the most superior in performance.

Table II gives the results of humidity atmosphere tests in which the samples were suspended in a closed cabinet provided with means of varying temperature and humidity. Temperature was controlled during the day to 55° to 60° C. by means of electrical heaters and an external resistance. Humidity provided by trays of water in the base of the cabinet was about 70% during the day. The test cabinet was allowzd to cool off at night with the humidity rising to 100%, and moisture condensing on the specimens. Under these conditions the various groups of specimens behaved relative to one another in the same way as under salt-spray conditions. It is particularly noteworthy how these relatively mild exposure conditions accelerated the deterioration of the finish on the untreated specimens and caused loss of adhesion in a short period.

Table III shows the durability of the same range of samples when exposed to open atmosphere without protection from weather conditions. They again show the futility of enamel finishes applied direct to the base metal without pre-treatment.

Table IV is of interest in showing the behaviour of the chemically treated specimens without any additional organic finish. It often so happens that when components are enamelled that certain areas have to be left without finish. The test results show that the chromate immersion process actually improves corrosion resistance of the zinc alloy. It also shows that the light phosphate processes B and D cause no deterioration in this respect, whereas the surfaces produced by the heavier processes A and C are liable to whiten by atmospheric corrosion rather more easily.

Table V merely summarises the various organic finishing materials used in the tests, showing their nature and consistency. They were all selected for being reasonable commercial products with respect to adhesion, resistance to ageing and smoothness of finish.

A recent article in *Zeitschrift für Metallkunde*, by Fischer and Budiloff, reviewed the merits of chemical and electrochemical treatment for zinc and zinc alloys. The alloys covered in their tests virtually included all the Mazak series and established mixtures. It points out that of the chemical dipping processes those using solutions containing chromate are the best, and it covers experimental work in some detail on electro-chemical methods in which the work is made the anode in solutions containing stannates, oxalates, permanganates, ferrocyanides and chromates. It is important that the treatment should give an insoluble basic zinc salt formed in intimate contact with the metal surface. Table VI summarises some of these solutions, the operating conditions and the appearance of the coating formed.

Pre-treatment of the specimens comprised degreasing in tri-sodium phosphate solution, with thorough water washing before the electrolytic process and, after the latter, water washing and drying off in an air current. The alloys treated included 4% aluminium, 3% copper, 4% aluminium 1% copper, and 4% aluminium with no copper. The

TABLE III.—DURABILITY TEST RESULTS—"FINISHED" ZINC BASE DIE CASTINGS EXPOSED TO OPEN ATMOSPHERE.

Sample No.	Organic Finish.	No Chemical Pre-treatment.	Phosphate Immersion Treatment.				Chromate Immersion Treatment.
			A.	B.	C.	D.	
1	Zinc chromate primer, stoved glossy brown finishing enamel, stoved.	Adhesion completely lost in four weeks.	Unaffected in eight weeks.	Unaffected in eight weeks.	Unaffected in eight weeks.	Unaffected in eight weeks.	Unaffected in eight weeks.
2	Red oxide primer, stoved glossy brown finishing enamel, stoved.	ditto	ditto	ditto	ditto	ditto	ditto
3	Two coats glossy brown finishing enamel, stoved.	ditto	ditto	ditto	ditto	ditto	ditto
4	Two coats glossy brown cellulose enamel.	ditto	ditto	Very slight embrittlement in eight weeks, condition good.	Condition good in eight weeks, although cellulose slightly brittle.	ditto	ditto
5	One coat aluminium cellulose enamel.	Adhesion poor in four weeks.	ditto	Satisfactory in eight weeks.	Satisfactory in eight weeks.	ditto	ditto
6	One coat aluminium stoving enamel.	Adhesion very poor in four weeks.	ditto	Unaffected in eight weeks.	Unaffected in eight weeks.	ditto	ditto
7	One coat aluminium, one coat stoving varnish.	ditto	ditto	ditto	ditto	ditto	ditto
8	One coat special clear cellulose lacquer.	Unaffected in six weeks.	Slight white corrosion in eight weeks.	ditto	ditto	Slight white corrosion in eight weeks.	ditto

TABLE IV.—DURABILITY TEST RESULTS—ZINC BASE DIE CASTINGS WITHOUT CHEMICAL TREATMENT, NO ORGANIC FINISH.

Sample No.	Chemical Treatment.	Durability Test Conditions.		
		Salt Spray.	Humid Atmosphere.	Open Atmosphere.
1	None	White corrosion within one week, general, and gradually developing to fairly marked corrosion in four weeks.	Unaffected in four weeks, few white corrosion spots in thirty weeks.	Few small white corrosion spots in four weeks, further slightly deteriorated in thirty weeks.
2	Phosphate A.	Fairly heavy corrosion at end of four weeks.	Gradual slight whitening, poor in thirty weeks.	White corrosion spots in four weeks, relatively pitted in thirty weeks.
3	Phosphate B.	Slight white corrosion in four weeks.	Unaffected in four weeks, few white corrosion spots in thirty weeks.	Slight corrosion in four weeks, and a little further deterioration in thirty weeks.
4	Phosphate C.	Fairly marked corrosion in four weeks.	Gradual slight whitening, poor in thirty weeks.	White corrosion spots in four weeks, relatively pitted in thirty weeks.
5	Phosphate D.	Slight white corrosion in four weeks.	Unaffected in four weeks, few white corrosion spots in thirty weeks.	Slight corrosion in four weeks, and a little further deterioration in thirty weeks.
6	Chromate Immersion.	Unaffected in four weeks.	Unaffected in four weeks, virtually unaffected in thirty weeks.	Unaffected in four weeks, and virtually no deterioration in thirty weeks.

ammonium-oxalite solutions gave uneven films, having no coherence, so they were not further considered.

The other specimens were subjected to corrosion tests in 3% common salt solution containing 0·1% of hydrogen peroxide, using the DVL agitator equipment. Results were compared with untreated specimens and with chromate-dipped specimens. Results are given in Table VII. These weight changes are not sufficiently discerning and visual examination is generally more valuable. On the latter standard, in eight days' corrosion test, untreated specimens and oxidised specimens from stannate and ferrocyanide solutions were very heavily corroded and the tests abandoned. The permanganate coatings, on the other hand, were appreciably superior, although still far inferior to the simple immersion chromate-treated specimens. The anodic chromate specimens were somewhat better than the chromate-dipped ones.

Anodic alkaline treatment was also explored, the electrolyte used being 2% caustic soda with carbon cathodes. A current density of 5 amps. per square decimeter was used at 5 v., and a treatment time of 15 mins. After-treatment consisted in water washing and drying off in an air current. Grey to black coatings were obtained which could be used for artistic purposes and they were examined for corrosion resistance with the additional protection of oiling with linseed oil or waxing. They were found to offer very little protection at all.

It was ultimately considered that the anodic-chromate solution was the best electrolyte to explore, and it was studied with stabilising addition agents. An improved electrolyte was developed which, at 0·5 amps. per square decimeter and 16 v., gave a thickness of coating of 10 μ in 20 mins. and 30 μ in 60 mins. The deposit became coarsely grained with longer times, and 20-min. treatment was recommended for most practical purposes.

Operating at room temperatures gives an olive-green coloured film almost independent of the alloy composition and of good coherence, whereas higher temperatures—for example, 40° and above—make the deposit spongy and porous. The coating, however, is absorbent, similar to anodic coatings on aluminium alloys, giving the possibility of colouring with dies, protecting with wax or oil, and providing a good base for paint and enamel. Figs. 1 and 2 give a comparison of the solubility rates of unprotected zinc, the ordinary anodic chromate, the anodic chromate with special additions and chromate dipping processes, in 3% salt solution.

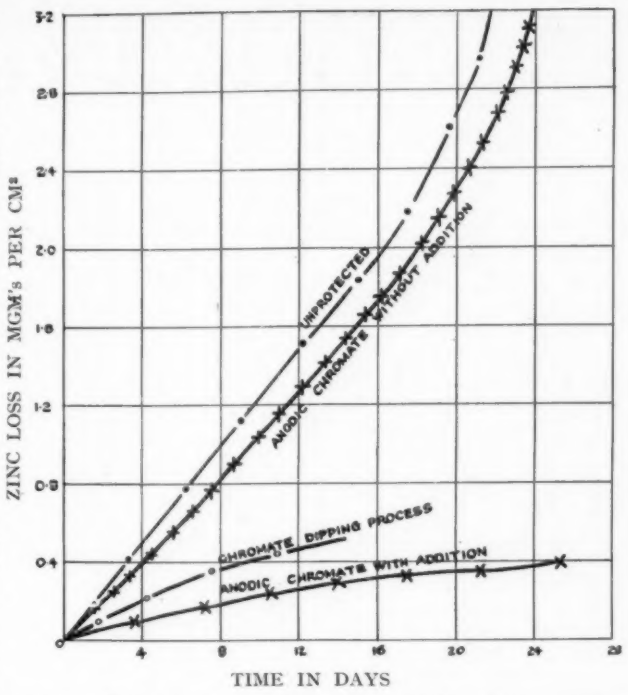


Fig. 1.—Zinc base die casting (4% aluminium, 3% copper) corrosion in 100 c.c. common salt solution (3%) at 20° C.

Using the anodic-chromate solution with addition agents the voltage rises to 16, still maintaining the low current density of 0·5 amps. per square decimeter, whereas the straight anodic chromate bath only reaches 6 v., with 1·2 amps. per square decimeter. As a result, the new type of coating is much closer grained than the older type. Also tested at 4 v., the resistance of the new film is of the order of 105 ohms as against 10 ohms for the old type.

TABLE V.

CHARACTERISTICS OF MEDIA USED FOR TESTS.

Medium No.	Description.	Chemical.		Physical.		Stoving Conditions.
		Volatile Spirit % (Loss, 3 hrs. at 110° C.)	Total Solids, %.	Specific Gravity at 25° C.	Viscosity Centi-poises at 25° C.	
1	Zinc chromate primer, stoving synthetic, oil modified glyptal.	57·0	43·0	1·075	250	30 mins. at 250° F.
2	Red oxide primer, stoving synthetic, oil modified glyptal.	37·5	62·5	0·900	750	30 mins. at 250° F.
3	Glossy brown enamel, stoving synthetic, oil modified glyptal.	56·8	43·2	1·060	310	30 mins. at 250° F.
4	Glossy brown cellulose enamel.	65·3	34·7	1·013	650	—
5	Aluminium cellulose enamel, ready mixed.	93·0	7·0	0·835	100	—
6	Aluminium stoving enamel, ready mixed, oil modified glyptal.	61·5	38·5	0·995	40	30 mins. at 250° F.
7	Stoving varnish, oil modified glyptal.	56·0	44·0	0·970	140	30 mins. at 250° F.
8	Special clear cellulose lacquer, cellulose/glyptal combination type.	87·5	12·5	0·878	12	—

TABLE VI.

BEHAVIOUR OF ZINC AND ZINC ALLOYS UNDER ANODIC TREATMENT IN VARIOUS ELECTROLYTES.

Electrolyte.	Current Density, Amps./dm.²	Tension, in Volts.	Bath Temperature, °C.	Period of Treatment, Mins.	Appearance of Coatings.
5% solution of sodium stannate.	3·8—4·8	6 (constant)	20	10—20	Whitish to light grey
5% solution of ammonium oxalate.	3	Rising to 110	20	20	Whitish, very uneven.
2% solution of potassium permanganate.	1·5	6 (constant)	50	10	Dark brown.
5% solution of potassium ferrocyanide.	2·5	6 (constant)	20	5	Colourless, slightly iridescent.
60% solution of potassium chromate.	0·5	6	20	10	Olive green.

TABLE VII.

SPEED OF SOLUTION IN 3% COMMON SALT SOLUTION AT 20° C.

Material.	Speed of Solution in Mg./cm.²/day.	
	Untreated.	Oxidised.
Zinc (99·95%)	0·072	0·071
SpGZn—Al4—Cu2	0·133	0·154
SpGZn—Al—4	0·083	0·029

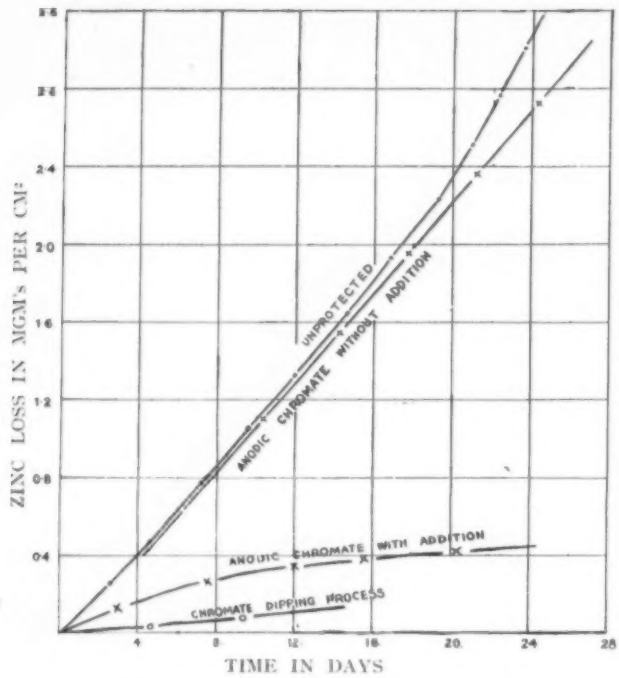


Fig. 2.—Zinc base die casting (4% aluminium) corrosion in 100 c.c. common salt solution (3%) at 20° C.

Moreover, the new film withstands pressure without short-circuiting.

The coatings for the tests covered by Figs. 1 and 2 were produced on alloys first pickled in 50/50 nitric acid for 10 secs. and then treated in cold 40% caustic soda solution for 5 mins. The chromate dip was 20 mins. at 20° C. With additions the anodic conditions were 0·5 amps. per square decimeter at 16 v. for 20 mins. All samples after treatment were washed in water and dried in air. No additional coatings were applied.

The authors therefore concluded that coatings produced by chromate containing electrolytes offered good protection against corrosion. Coatings from other electrolytes produced very little protection. Black deposits from alkaline solutions are only useful for decorative purposes and for indoor use. The suitable additions for still further improving the chromate electrolytes, unfortunately, are not named, and it is hoped to see a continuation of this work at a more opportune time.

It will be seen from the foregoing that the enamelling or lacquering of zinc alloys is straightforward. The enamelling itself utilises existing media and methods—spray or dip or brush, air drying or stoving. Pre-treatments are, however, inevitable, but the plant, techniques and control are those normal to modern industrial finishing shops. Zinc die castings are taking a more prominent position in engineering and have come to stay. It behoves users, therefore, to study the problem and adopt from the outset sound finishing methods best suited to their product. Any of the pre-treatments discussed are acceptable, and their reliative merits have been elucidated. Regarding enamels, stoving synthetics are always best. They are uniform in quality, easy to apply, rapid in baking, and of excellent durability. When air drying media must be used, cellulose products are satisfactory, but it is strongly advocated that one of the longer phosphate processes be adopted in such cases for chemical pre-treatment, or the chromate process. Ultimately, it is hoped that anodic electrical chromate processes will be established on a commercial basis.

Hot-Tinning Cast Iron

Coating metals with tin by dipping them into the molten metal is still the most widely used method of tinning. In this article the hot-tinning of grey cast iron is discussed, and the need for care in the preparation of castings is emphasised.

THE tinning of grey cast iron is complicated by the presence of flakes of graphite in the metal, which may cause the tin coating to de-wet badly, and in some cases prevent it from adhering at all. Careful preparation is therefore necessary, and with some grey irons it is essential to apply a preliminary electro-deposited coating to which the tin will adhere satisfactorily. Malleable iron, on the other hand, is usually quite easy to tin by ordinary methods.

In the preparation of castings care must be taken to avoid prolonged pickling. Cast iron is readily attacked by acids, and if it is pickled long the surface becomes pitted and acid is absorbed around the flakes of graphite. Moreover, a sludge of graphite is left behind when the iron is dissolved, and it is often difficult to remove from the surface. For this reason it is usual to carry out most of the preparation by mechanical means, and to pickle for a few minutes only.

Either sand- or shot-blasting or tumbling may be employed, depending upon the articles to be treated and the equipment available. Since the castings produced by different foundries vary considerably as regards surface finish, it is difficult to make any definite recommendations. It may be said, however, that tumbling is generally preferred for small articles, such as mincer parts, while large castings must be sand-blasted. The only requirement is that the sand and scale should be removed, and the surface left smooth and free from grease. When sand-blasting is employed care must be taken to avoid the presence of oil in the supply of compressed air.

The pickling procedure depends to some extent on the previous treatment. When the articles have been tumbled, there is generally nothing to be removed other than a thin film of graphite which has been spread over the surface by the burnishing action of the tumbling operation. This is quite easily removed by pickling for about five minutes in the usual cold hydrochloric acid solution, or for about two minutes in hot sulphuric acid. The hydrogen evolved by the attack of the acid on the iron pushes off the film of graphite. After sand-blasting, or when traces of moulding sand remain in the surface after tumbling, it is advantageous to use a cold 5% solution of hydrofluoric acid. This attacks and loosens adhering particles of sand. Since it also attacks glass and earthenware, the pickling operation should be carried out in a vat lined with lead or rubber and rubber gauntlets must be worn. After pickling, the castings are washed and then stored in a vat of water, slightly acidified with hydrochloric acid, until required. If the castings are made from iron which can be tinned satisfactorily without further treatment, the tinning operation is then proceeded with. If, on the other hand, the iron has unsatisfactory tinning qualities, a suitable undercoat must first be applied to it.

The best coating for this purpose is electro-deposited iron. A copper coating is sometimes suggested, but is not satisfactory. If the coating is thin (e.g., as obtained by chemical displacement) it is dissolved by the tin during the tinning operation and the surface of the cast iron is exposed again, particularly as the time of immersion of castings in the tin bath is necessarily longer than that employed for

sheet metal, on account of their greater thickness. A relatively thick coating of copper permits of good tinning, but the tin bath becomes contaminated by copper dissolved from the plated castings and the brightness of the resulting tin coating is impaired. An electro-deposited iron coating is, however, quite easily applied, and is not dissolved to an appreciable extent by the molten tin.

Several different baths are available for iron plating, but a convenient one consists of a solution containing 3 lb. per gallon of ferrous ammonium sulphate. This is used with anodes of mild steel or ingot iron, and the current density on the cathode (the articles being plated) should be about 10–15 amp. per sq. ft. The bath is worked at room temperature, but if it falls below about 18° C. (65° F.), the current density should be reduced. Too high a current density leads to the formation of a rough deposit at projecting parts of the article being plated. The solution has a rather poor throwing power, and for plating hollow articles it may be necessary to hang an auxiliary anode inside. Plating is continued until the casting is completely covered with a light-grey deposit of iron, which should be smooth and uniform.

The pH of the plating solution is important, and this tends to change in the direction of greater acidity when the bath is not being used. The acidity is corrected by adding dilute ammonia solution until the pH is adjusted to about 5·8, as indicated by a bromo-cresol purple indicator.

After the castings have been plated, they are tinned as soon as possible, being kept in slightly acidified water until required. The freshly deposited iron rusts rapidly if left in the air; it is also readily attacked by acid, so that the acidity of the water in the storage vat must be very low.

Fluxing and tinning are carried out by the standard procedure described in section 9, p. 11, two pots of tin being used for the best work. Sufficient time must be allowed for the casting to reach the temperature of the tin in the first pot, but the immersion in the second pot may be quite brief.

The draining and cooling of the tinned castings call for special mention. Cast iron articles are of relatively thick section and therefore retain their heat for a considerable time after removal from the bath. If they are allowed to cool in the air the coating drains for too long a time, and the tin on the uppermost parts becomes too thin to give a bright, smooth finish. Moreover, when tinned articles remain hot for a long time the tin oxidises and becomes yellow. It is usual, therefore, to shake off the surplus tin from the castings and then to cool them by quenching in oil. Paraffin (kerosene) is suitable for this purpose, provided that the volume of oil is large in proportion to the size of the castings, and the danger of fire is thus avoided. Alternatively, a heavier oil of higher flash point may be used, this being heated to 100°–150° C. (212°–300° F.) when starting work, so as to make it fluid; in this case it may be necessary to wash off the heavier oil in paraffin afterwards. Finally, the castings are cleaned in sawdust or sharps.

The process described above is not used when tinning articles such as saucepans, which are only required to be coated on the inside. The wiping process is used for such articles, which are first plated with iron if the quality of the castings makes it necessary.

Tinning by Wiping

Cleaning and pickling are carried out by the usual methods, and the articles are then washed and dried as quickly as possible to avoid oxidation or corrosion. The articles are then heated over a fire or gas burners to a temperature somewhat above the melting point of tin. Finely powdered ammonium chloride is sprinkled on to act as a flux, and tin is applied by rubbing the heated surface with a stick of tin. In some instances it is found convenient to pour a little molten tin into the vessel, pouring out the surplus into the next vessel when the wiping is finished; this is the procedure adopted with iron saucepans. The tin is wiped round, using more flux as required, until a smooth, continuous coating is obtained. The wiper may consist of a cork mounted on a stick (for small vessels), rag, tow, steel wool, etc. Since the finished coating is usually a little dirty from dross and burnt residues left by the charring of the wiper, the articles are often scoured afterwards with silver sand.

The above notes are extracted from a booklet recently published by the Tin Research Institute, Fraser Road, Greenford, Middlesex, which discusses the processes used in hot-tinning fabricated articles of various kinds. It is based upon the experience and information accumulated by the Institute over many years. The booklet is prepared by C. E. Homer, B.Sc., Ph.D., and deals with the hot-tinning of steel and iron, and of copper and copper alloys. Copies may be obtained on application to the Institute.

Quenching Stresses in Aluminium Alloys

A STUDY has been made by Professor Dr. A. von Zeerleder* of the internal stresses in Avional D alloy set up by quenching, and of the possibility of eliminating them by subsequent cold-work. The tests were carried out with extruded bars of 50 mm. diameter, which had been made from billets of 200 mm. diameter cast in ordinary iron moulds. The alloy studied had the composition: Copper 4·0, silicon 0·2, magnesium 0·6, manganese 0·5, iron 0·2%, and aluminium the remainder.

Heat stresses occur to the greatest extent when heated materials are quenched. By a rapid cooling of the material its thermal expansion is suddenly reversed. During the cooling of a round billet by quenching the outer layer cools more quickly than the core, and because of the volume contraction shrinks on the core, which has not yet begun to contract—i.e., the outer layer is submitted either to elastic strain or to over-straining. As a result of the subsequent cooling of the core, a state of equilibrium is next set up between the stretched outer zone and the compressed core. With further cooling of the core a reversal of the stresses takes place, as the contraction of the core continues, and the core is thereby subjected to tension. The outer layer will therefore experience compressive stresses.

The method used for determining the stresses consisted in measuring the dimensional changes of the stock during step-by-step removal of the outer layers. Several methods for measuring the internal strains have been developed. In the present investigation, as it was not intended to determine the stresses with great exactitude, the accurate method of Sachs was not employed, and measurements were made by the simpler but somewhat less precise method of Heyn and Bauer. Although figures obtained by this method are too low, since the method takes into consideration only the unidirectional longitudinal strain, it was sufficient for the present purpose.

The present investigation shows that the magnitude of the internal stresses does not increase with greater diameters; quenching tests with 200 mm. round billets and 50 mm. round bars gave rise to strains of almost the same magnitude. These cooling stresses often cause distortion or warping, and sometimes even tearing, during the working of solution heat-treated materials.

The variables studied were: Time between solution treatment and quenching, temperature and nature of quenching medium, temperature of ageing, and cold-working before and after ageing. It is shown that the stresses are greatest on quenching in water at 20° C., and decrease as the temperature of the water is increased. They are small after quenching in oil, and are practically independent of its temperature. They are materially reduced or even reversed by cold-working before and after ageing.

* *Jour. of Inst. of Metals*. Part 3, **67**, pp. 87–99.

Developments in Metal Extrusion

As a result of ceaseless metallurgical research and improved hydraulic presses, stainless steels, nickel alloys, bearing steel, etc., as well as non-ferrous alloys are now being extruded into tubing, rods and sections.

THE extrusion of non-ferrous metals into rods and simple sections has been a commercial success for over thirty-five years, but it is only during recent years that the process has been applied to the production of stainless steel, nickel alloy, and bearing steel tubing, rods and sections, and, in many cases, manufacturing costs have been materially reduced over the older methods. This development, which appears likely to open new fields for several special alloy steels, is discussed by A. B. Cudebec,* of the Loewy Engineering Co. Ltd., who states that it has been made possible, not by any new or startling discovery, but rather by ceaseless research in metallurgy and a gradual improvement in the design of the hydraulic press.

The first commercial production of ferrous alloy tubing by extrusion was the 18–8 stainless steel, but this was quickly followed by other stainless alloys containing 17% chromium and 12% chromium. Research and experimental work was undertaken to produce Monel metal tubing, and to-day the extrusion of tubing, as well as numerous other sections in nickel alloys, is a normal production process. Exclusive trials were recently made on bearing steel, and the results indicate that this difficult alloy will eventually be extruded commercially into tubing.

The designers of extrusion plant have concentrated their recent efforts particularly in the field of stainless steels and other special ferrous and non-ferrous alloys which do not work well by rolling, welding or piercing, but which now can be commercially extruded. Several such alloys are being extruded in large quantities in Britain but they have not yet been commercialised in the United States.

For many alloys the advantages of extrusion over rolling and drawing are not as yet widely known. It would appear true to state that any metal which has been extruded from a cast billet has by this process acquired a grain structure more free from faults than if it had been rolled. This change of structure is probably due to the fact that extrusion is a squeezing-compression process, while piercing, rolling, and drawing are stretching operations. Moreover, there are some special alloys which cannot be successfully rolled at all without developing serious faults which render them unfit for certain commercial purposes.

The extrusion process does not compete in the ordinary field of carbon steel, and is only commercially interesting in handling expensive ferrous alloys and all non-ferrons products. This field, however, is very wide, and special alloys are now being substituted for heavier parts in almost every branch of mechanical engineering design.

Many variables are encountered in the extrusion of special alloys. Each alloy appears to have its own extrusion temperature, which ranges from 425° to 485° C. for aluminium up to about 1,200° to 1,255° C. for cupro-nickels, bearing and stainless steels. Some of the alloys must be held to a range of only 5° C. temperature variation to obtain successful products by extrusion. Other variables include troubles which arise from heating billets too rapidly or too slowly, and the speed with which the extrusion must be made. If the extrusion is too rapid, the metal may tear, while if too slow, or the billet is too cold, the billet may stick to the container wall.

Research in press design and in metallurgy has recently been rewarded by the successful production of much larger presses than formerly existed. These advances have received an impetus with the concentration of industry on war-work and presses are in use in Britain possessing capacities up to 6,600 tons. They are equipped with containers up to 48 in. long with a diameter of 20 in., and operate at 4,500 lb. per sq. in. hydraulic pressure.

About 50% of the extruded products are finished profiles which only require straightening and in some cases heat-treatment before being completed. The remaining 50% of the production is extruded into round bars, strips and other half-finished products. This latter material constitutes raw material for the subsequent processes of forming into various components, mostly by cold-rolling or pressing. Extruding the metal assists it to acquire malleability while still retaining its tensile strength and uniform grain structure in the finished product.

It is doubtful whether the large modern extrusion press, ranging from 4,000-ton to 6,600-ton capacity, would ever have been developed had it not been for the pistonless air-hydraulic accumulator with which it is driven. The older type of weighted accumulator would have presented almost insuperable obstacles against obtaining a satisfactory control, which is so essential in operating a large modern press. It is believed that the largest pistonless hydraulic accumulator now in regular operation is associated with an industrial plant in Britain. It has a useful water capacity of 2,900 gals. operating at 3,150 lb. per sq. in., and supplies hydraulic pressure for operating not only what is claimed to be the largest drawing press in the world, but also a 5,000-ton piercing press and other hydraulic equipment located at different points in a modern steel plant.

Surface scale caused by oxidation has for years been one of the tough problems to be solved since metal extrusion first came into practice. Some manufacturers still follow the method of scalping the surface of the billets before extrusion. Most manufacturers, however, now extrude the billets without scalping and leave a thin skin shell in the container after the extrusion cycle is completed. This shell is quickly and economically removed by pushing a tight-fitting dummy block through the container immediately after the extrusion is completed. This process takes only a few seconds between pushes, and the extruded products are found to be as completely free from oxidation as though the billets had been previously scalped.

The butt ends of billets cannot be entirely extruded, whether billets are ferrous or non-ferrous. These butt ends must be cut from the extruded piece. The amount of scrap loss from this cause depends upon whether tubes, rods or sections are being extruded. In modern presses the amount of scrap, which includes the butt end and the shell previously mentioned, now ranges from 8 to 10% for tubes, and from 10 to 12% for rods and sections. Extruded metals are expensive, however, and scrap metal must be kept low.

Tubing can be commercially extruded in sizes from a minimum of 1¼ in. to 4 in. or 5 in. outside diameter depending upon the capacity of the press. Experience has shown, however, that 75 to 80% of the demand for alloy tubing is for sizes below 3 in. diameter. In order to provide a maximum tonnage, tube extrusion presses are usually operated to produce as few different diameters as possible, always of the upper range sizes. These tubes, known as "blanks," are then drawn cold to the smaller sizes. There is no practical upper limit to the wall thickness which can be economically extruded, but the minimum thickness for most alloys is about 0·16 in. It is cheaper, however, to draw down from thicker walls than to extrude direct to this minimum dimension, as the wear upon dies increases rapidly with thinner walls.

* *Mechanical Engineering*, vol. 63, No. 1, pp. 16-18.

Reviews of Current Literature

Empire Mineral Resources and their Relation to the War Effort

NATURE has not taken into account the political boundaries of nations in its distribution of mineral supplies. Some minerals are so widespread that nearly all countries have adequate supplies within their own boundaries, or at least near at hand. Other minerals are so distributed that some parts of the world have a surplus and others a deficiency. No country is entirely self-sufficing in regard to either supplies or markets for all mineral commodities, so that international exchange of minerals cannot be avoided if all nations are to be supplied with needed materials. In peace-times the necessary international movement of minerals may be aided or hindered by various artificial means, but the international channels of mineral movement are not altered by legislation. When a major war is in progress, however, the situation is radically changed, and supplies of minerals may cease to be available to some countries through difficulties of transport.

Europe, as a whole, apart from Russia, is not very well endowed with mineral resources, and though some countries are better off than others, no single one, and, indeed, no contiguous group, is self-sufficing. And yet, within the British Empire itself there are sufficient metals and minerals not only for its own requirements, but in most cases to provide a surplus for use by other countries against which she is not at war ; further, she is in a position to transport her supplies from overseas. Many volumes have been published describing the occurrence and exploitation of the mineral deposits of the British Commonwealth of Nations, but this book of 86 pages presents an interesting and informative résumé of the Empire's mineral resources and their relation to the war effort. It presents the twenty-third Streatfield Memorial Lecture delivered before the Institute of Chemistry last year by the Principal of the Mineral Resources Department of the Imperial Institute.

The subject matter is considered in three sections : the first dealing with the Empire's share of mineral wealth compared with that of the remainder of the world in the production of minerals essential for industry and war ; the production, uses and trade of minerals and metals of the Empire are considered in the second section, and details are given of recent overseas developments to meet increased demands occasioned by the war ; and in the final section brief reference is made to the assistance given by the Government to the mining industry of the Empire overseas.

The minerals and metals are arranged under seven headings which deal with mineral fuels, iron and ferro-alloy minerals, base metal minerals, precious metals and stones, minerals for the chemical industries, industrial earths and clays, and miscellaneous non-metallic minerals. This is a very informative and useful book.

By Sydney J. Johnstone, B.Sc., F.I.C. Published by the Institute of Chemistry of Great Britain and Ireland, 30, Russell Square, London, W.C. 1.

The Sampling and Chemical Analysis of Cast Ferrous Metals

THE first report issued by the British Cast Iron Research Association's Tests and Specifications Sub-Committee on recommended methods for sampling and analysis of cast ferrous metals and alloys was published in 1929. The second edition was issued some four years later and has now been out of print for some time. The present, third edition supersedes the earlier editions ; it has been re-written and enlarged, and is issued in response to demand in spite of difficulties due to war-time conditions. The subject is presented in three parts, the first dealing with plain, the second with alloyed, materials, and the third with ferro alloys, which find an increasing use in foundry practice.

In its present form this work represents the most comprehensive collection of methods available for the sampling and chemical examination of cast ferrous metals, excluding steel, though the majority of the methods are applicable to this material. It covers the determination of all the elements commonly found in white and grey cast iron, pig iron and malleable cast iron. Methods are also described for ascertaining the amounts of less common elements present in these materials ; 23 elements are dealt with in all. It includes a completely new section dealing with the examination of ferro-alloys.

General laboratory technique is described ; many of the procedures given in the earlier editions have undergone considerable modification and much new material covering recent analytical developments has been incorporated in the text. Alternative methods are given in many instances, and their comparative accuracy and limitations are critically discussed. The basic chemical principles underlying each procedure are separately treated in order to assist understanding of any particular process. Recommended analytical tolerances are given and notes are included on the care and maintenance of platinum apparatus.

The book is primarily intended for those requiring to make chemical analyses of pig irons (grey or white, blast-furnace or refined, plain or alloyed), white or grey cast iron (plain or alloyed), malleable cast iron, special cast irons (austenitic, martensitic, etc.), or ferro-alloys. The presence of graphite carbon in grey iron frequently leads to complications in analytical procedure which are not encountered in the examination of steel samples. The methods given have been tried and used over a period of years in the Association's laboratories and are especially useful to chemists and metallurgists in works and other laboratories engaged in acceptance tests on raw materials and products, either in process of manufacture or finished.

Third edition, revised and enlarged by E. Taylor Austin, F.I.C. Special Publication No. 7 of the British Cast Iron Research Association, 21, St. Paul's Square, Birmingham, 3. Price 15s. post free.

Chemical Analysis of Aluminium

METHODS for the analysis of aluminium and aluminium alloys differs from methods used for other metals mainly in the preliminary steps of solution and separation ; the actual determinations are, in general, the same. The property of dissolving readily, not only in certain acids, but also in alkali hydroxides, differentiates aluminium from most other metals. This property effects the necessary separations of the aluminium from several constituents, as, for example, copper or nickel, since they remain practically insoluble when the aluminium is dissolved in caustic solution. Sodium hydroxide, therefore, is serviceable for starting analyses involving the determination of these constituents. For other determinations, such as iron and manganese, acids are used to dissolve the sample, with reliance on later treatments to separate or distinguish the element sought.

The methods presented in this book have stood the test of practical use and evaluation in the plant laboratories of Aluminium Company of America and in the Analytical Division of Aluminium Research Laboratories. This edition incorporates revisions in methods given in the 1937 edition, and includes new material. For an accurate quantitative estimation of the content of a particular element in a sample it is obvious that the problem is to put the element to be determined in such a condition and environment as will permit its measurement without interference ; in this book, therefore, great emphasis is placed upon procedures prior to actual measurement.

The subject is presented in five chapters. The first gives

a very interesting summary of the development of methods of analysis, and also deals with the solution of aluminium and the separation of aluminium. The second chapter is partly concerned with the impurities in metallic aluminium and with routine analysis for common impurities, but the major part is devoted to a consideration of the elements commonly alloyed with aluminium, such as silicon, iron, copper, manganese, zinc, lead, magnesium, nickel, chromium, and tin. Procedures for the determination of these elements in aluminium alloys is given. Methods for the rapid determination of silicon, iron, copper, manganese, magnesium, chromium and titanium are given in the third chapter, while in another section considerable attention is given to the determination of less common constituents of aluminium alloys. The final chapter is devoted to methods for the examination of Albron powder and paste. The tests for the most part are physical rather than chemical.

This work will be invaluable to the increasing number of chemists and metallurgists who now deal with aluminium and its alloys in their various forms.

Published by Aluminium Company of America. Copies may be obtained from Aluminium Research Laboratories, New Kensington, Pa., U.S.A. Price 50 cents.

The Hilger Non-Recording X-Ray Micro-Photometer

THE type of microphotometer employed for the density measurement of photographed spectrum lines is not usually very satisfactory for the examination of X-ray diffraction diagrams as the magnification is too high to be effectively utilised for the relatively diffuse lines and large grain of X-ray film negatives. To meet this need Adam Hilger Ltd. has designed a special instrument in which due regard has been taken of the features which make it most suitable for such work. In addition to its normal functions of measuring blackening it is capable of linear measurement over a range of 15 cms. to an accuracy of 0·01 mm. Particulars of this instrument are given in a pamphlet recently issued by Adam Hilger Ltd., Camden Road, London, N.W. 1.

Plant for the Melting of Aluminium and its Alloys

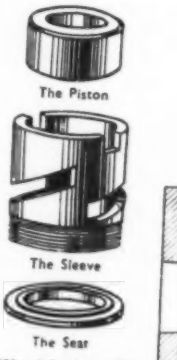
Consistent and successful results in the routine melting of aluminium alloys depends largely upon the design, construction, control and use of furnaces. This is, of course, true of all metals to be melted, but it applies with added force to aluminium alloys because, in spite of their relatively low melting points, they entail special considerations which are dictated by the chemical reactivity of the molten metal. This subject is admirably discussed and illustrated in the current issue of *Aluminium Technique*.

As for other metals and alloys, the heating medium used may be a solid fuel (usually coke), oil, gas (mainly coal gas), or electricity. For melting purposes successful examples may be cited of the use of all four systems. The necessity for preventing contamination of a light metal melt favour the use of electricity; on the other hand, correct furnace design and careful supervision of the fusion process tend largely to offset any possible disadvantages which might be attributed to liquid or gaseous media. Selection should not be based solely on a thermal balance-sheet; it should be made with due regard to technical and economic requirements, and the efficient use of the medium selected necessitates correct furnace design and construction, and correct furnace operation.

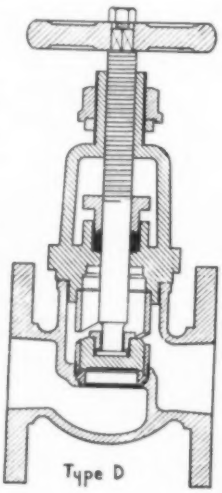
The many types of furnaces applied to the melting of aluminium alloys are discussed in this booklet, and labour, fuel consumption, and melting times are briefly considered. Copies may be obtained from Aluminium Union, Ltd., The Adelphi, Strand, London, W.C. 2.

Arkon Seat-in-Sleeve Valve

IT is well known that the most frequent cause of valve breakdown is wearing of the seat by steam whilst the valve is in a slightly open position. This can usually be attributed to the necessity for working valves in the "cracked" position when very fine regulation is required and the valve only just open to allow the passage of small quantities of steam. Apart from stoppages for disc renewal and regrinding of seats, there are also maintenance costs continually involved.



Working parts of the Arkon seat-in-sleeve valve.



Sections of the two types of the seat-in-sleeve valve.

A valve specially designed to eliminate wire-drawing is the improved type Arkon seat-in-sleeve valve. In this valve the stainless steel seat is protected by a sleeve in which the valve clack moves. Ports are cut in the sleeve so that no steam passes until the valve clack clears the ports. The clack is then well clear of the seat, and all wear due to the sudden rush of steam is taken by the sleeve. No matter how worn the ports in the sleeve become, the valve will shut tight when screwed down on the seat. Thus, with the valve only just open it is possible to get very fine regulation whilst not subjecting the seat to the damaging effects of "wire-drawing."

Two types are manufactured: "B" for saturated steam up to 150 lb. pressure, and type "D" for superheated steam up to 650° F. and 300 lb. pressure. They are made by Walker, Crosweller and Co., Ltd., of Cheltenham, and are available in all the usual pipe sizes with screwed or flanged connections.

Monel Notes—23

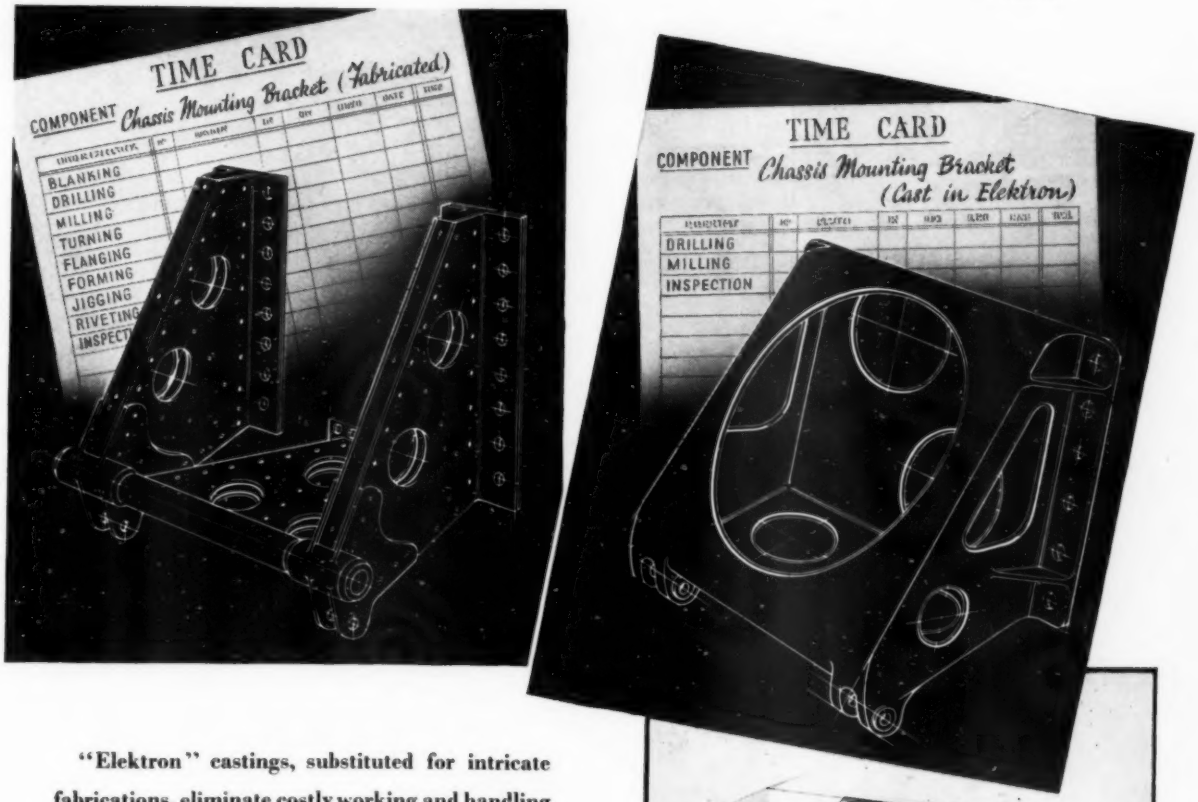
Monel Notes–23, which has just been published, contains articles primarily of interest to fabricators. Abridged instructions on the forging of Monel, nickel and Inconel are given, together with a description of suitable methods of bending pipe in these three metals. Some short notes on permissible shear loads and welding are included.

Copies may be obtained, free of charge, from Henry Wiggin and Co., Ltd., Grosvenor House, Park Lane, London, W. 1.

The proprietors of British Patent No. 491673 for Improvements relating to Manganese Steel, are desirous of entering into negotiations with firms in this country for the exploitation of the above invention either by the sale of the patent rights or by the grant of Licences to manufacture on royalty. Enquiries should be addressed to ABEL AND IMRAY, QUALITY HOUSE, QUALITY STREET, LONDON, W.C. 2.

"Look here on THIS picture and on THIS"...

—*Hamlet*



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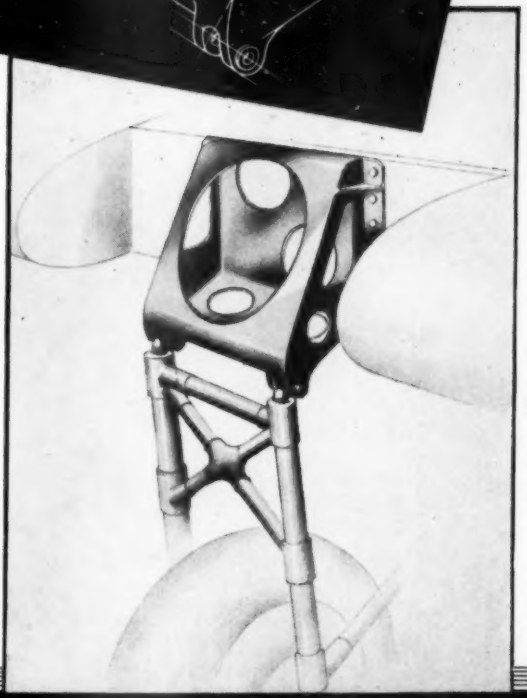

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METALLURGIA. Contents. For APRIL, 1941.

	Page
A Large Gas-fired Installation for the Heat-treatment of Forgings *A recent installation of batch type furnaces is described.*	161–163
Barium and Its Minerals. By L. Sanderson *Barium is of importance as an alloy with other metals for special purposes.*	163–164
Post-war Reconstruction Based on Price Stabilisation	165
The Austenitic Decay of a Vanadium Steel in an Undercooled Condition	166
Recent Research in Problems of Powder Metallurgy. By D. W. Rudorff, A.Am.I.E.E., M.Inst.F. *A review is given of recent laboratory research made into certain theoretical and practical problems of powder metallurgy.*	167–170
Corrosion Fatigue of Notched Cast Iron Specimens *Results are given of some recent corrosion fatigue experiments on unnotched and notched specimens of cast iron.*	170
The Formation and Properties of Martensite on the Surface of Rope Wire. By E. M. Trent, M.Met., Ph.D. *The occurrence of thin layers of martensite on the worn surfaces of wires in wire ropes used in mining.*	171–174
Complex Copper - Cobalt - Silicide Alloys *Results are given of experiments carried out on two copper-cobalt-silicide alloys, one having beryllium added and the other phosphorus.*	174
High Temperature Metallic Resistor Furnaces *Furnaces are described in which the resistors are composed of molybdenum or tungsten, by which temperatures up to 2,000° C. are attainable.*	175–177
Unsoundness in Gravity Die-cast Silicon-Aluminium Alloy Pistons	177
Atmospheric Exposure Tests on Copper Bearing and other Irons and Steels in the United States	178
The Practice of Marketing Aluminium.—Part III. By R. J. Anderson, D.Sc. *The marketing of aluminium and its manufactures when hostilities cease will be necessarily conditioned by the kind of products and their field of use.*	179–181
Organic Finishes on Zinc Base Die Castings. By E. E. Halls *Two main types of chemical pretreatment, to render the surfaces of zinc die castings inert.*	182–186
Hot-tinning Cast Iron *The hot-tinning of grey cast iron is discussed and the need for care in the preparation of castings is emphasised.*	186–187
Quenching Stresses in Aluminium Alloys	187
Developments in Metal Extrusion *As a result of ceaseless metallurgical research and improved hydraulic presses, stainless steels, nickel alloys, bearing steel, etc., as well as non-ferrous alloys are now being extruded into tubing, rods and sections.*	188
Reviews of Current Literature *Empire Mineral Resources and their Relation to the War Effort.*	189–190

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